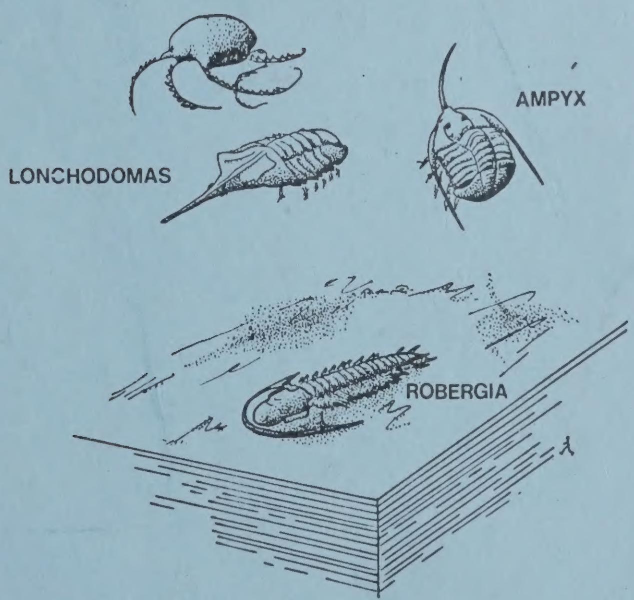
MIDDLE ORDOVICIAN CARBONATE SHELF TO DEEP WATER BASIN DEPOSITION IN THE SOUTHERN APPALACHIANS

Field Trip 10

EDITED BY

Kenneth R. Walker, Thomas W. Broadhead, Fred B. Keller
University of Tennessee, Knoxville 37916

1980



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DEPARTMENT OF GEOLOGICAL SCIENCES

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MIDDLE ORDOVICIAN CARBONATE SHELF TO DEEP-WATER BASIN DEPOSITION IN THE SOUTHERN APPALACHIANS

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Cover: Lower slope, trilobite assemblage by K. Walker

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Geology.

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SCALE OF ALL ROUTE MAPS 1 : 250,000

KEY TO FORMATION SYMBOLS USED ON DAILY ROUTE MAPS

Scale of all route maps = 1:250,000

MISSISSIPPIAN
- Mp - Pennington Fm.
- Mn - Newman Fm.
- Mfp - Fort Payne Fm.
- Mgg - Greasy Cove & Grainger Fms.
- Mg - Grainger Fm.

MISSISSIPPIAN - DEVONIAN
- MDc - Chattanooga Sh.

DEVONIAN - SILURIAN
- DSs - Sneedville Ls.

SILURIAN
- Src - Rockwood & Clinch Fms.
- Sr - Rockwood Fm.
- Sc - Clinch Fm.

ORDOVICIAN
- Os - Sequatchie Fm. — Oj - Juniata Fm.
- Och - Chickamauga Grp.
- Omb - Martinsburg Sh.
- Olmc - Lower & Middle Chickamauga Grp.
- Ob - Bays Fm.
- Oo - Ottosee Sh.
- Oh - Holston Fm.
- Ol - Lenoir Fm. — Osv - Sevier Sh.
- Oa - Athens Sh.
- OЄk - Knox Grp.
- Oma - Mascot Dolo. — On - Newala Fm.
- Ok - Kingsport Fm.
- Olv - Longview Dolo. — Ojb - Jonesboro Ls.
- Oc - Chepultepec Dolo.

CAMBRIAN
- Єcr - Copper Ridge Dolo.
- Єc - Conasauga Grp.
- Єmn - Maynardville Ls.
- Єn - Nolichucky Sh.
- Єm-- Maryville Ls.
- Єrg - Rogersville Sh.
- Єrt - Rutledge Ls. — Єhk - Honaker Dolo.
- Єpv - Pumpkin Valley Sh.
- Єr - Rome Fm.
- Єs - Shady Dolo.
- Єchi - Chilhowee Grp.
- Єhe - Hesse Ss. — Єe - Erwin Fm.
- Єmu - Murray Sh.
- Єni - Nichols Sh. — Єh - Hampton Fm.
- Єch - Cochran Congl. — Єu - Unicoi Fm.

PRECAMBRIAN
- pЄo - Ocoee Supergroup

FOREWARD

by
Kenneth R. Walker, Department of Geological Sciences,
University of Tennessee, Knoxville, Tennessee 37916

This field guide is dedicated to John Rodgers on the occasion of his semiretirement from the faculty of the Department of Geology and Geophysics at Yale University. Two of the authors benefited from his teaching and guidance as graduate students, and we have all "stood on his shoulders" in pursuing the research in the Ordovician of the Southern Appalachians which is reported here.

The present book was designed primarily to guide the participants in a four and one half day field trip held in conjunction with the 1980 National Meeting of the Geological Society of America. We have, however, planned each stop so that it can be used independently. The text referring to each stop is a separate, more or less self-contained scientific article which stands alone as a piece of research. Thus, the guide is assembled much as a symposium volume on the overall topic. The volume represents a report on research done at the University of Tennessee since about 1970 and on continuing projects. From 1970 to 1977 the research was done by Kenneth R. Walker and various masters and doctoral level students. In 1977, Fred B. Keller and his students joined the research and in 1978 Thomas W. Broadhead and his students began to participate. We have benefited throughout from thoughtful collaboration by Leonard P. Alberstadt and his students of Vanderbilt University (Nashville, Tennessee). The project continues at present with all three faculty and many students involved.

The research by Walker and his students has been supported by NSF Grants DES 72-01611 A01 and EAR 76-11808 A01. Work by Walker, Broadhead and students is now being supported by NSF Grant EAR 7927268. Broadhead and Keller have also been supported by grants from the University of Tennessee Faculty Research Fund. We also wish to thank the Penrose Bequest of the Geological Society of America and the Society of Sigma Xi for various grants to student participants in the project. Finally, over the years the research has benefited from many small but seminal grants from the Department of Geological Sciences at the University of Tennessee, especially from the Don Jones Fund, the Exxon Foundation Fund, the Mobil Foundation Fund, the Gulf Foundation Fund, and the Professors Honor Fund. Part of the publication costs for this guide were derived from NSF Grant EAR 7927268 to Walker and Broadhead and from the Professors Honor Fund of the Department of Geological Sciences at the University of Tennessee.

Copies of this giudebook may be purchased from the Department of Geological Sciences, University of Tennessee, Knoxville, Tennessee, 37916.

INTRODUCTION TO THE STRATIGRAPHY AND PALEOENVIRONMENTS OF THE MIDDLE ORDOVICIAN OF TENNESSEE (SOUTHERN APPALACHIANS, U.S.A)

Kenneth R. Walker, Dept. of Geological Sciences, Univ. of Tennessee, Knoxville, Tennessee 37916

This article presents an overview of the complex stratigraphy and paleoenvironmental pattern displayed in this sequence. The reader is referred to the various articles on specific field stops as well as Benedict and Walker, 1978, and Shanmugam and Walker, 1978, 1980, for a much more detailed treatment of specific parts of the environmental pattern. I am indebted to my former students for much of the data upon which this summary is based. An extensive treatise on the stratigraphy is now in preparation for publication elsewhere.

Much has been written about the chronostratigraphy of this sequence based on biostratigraphic studies, yet there is little agreement in the literature. In spite of this, the type sections or areas of four of Cooper's (1956) stages occur in or near the area of investigation. The initial thesis in our work was that studying the stratigraphy in terms of depositional environments would allow solution of the controversies. Although few of our interpretations resemble previous ones in detail, we acknowledge our great debt to the groundwork laid by G. A. Cooper, B. N. Cooper, John Rodgers, R. B. Neuman, Josiah Bridge, and many other previous workers. Many of our chronostratigraphic conclusions have been independently confirmed through conodont analyses by Bergstrom and his students (e.g. Bergstrom, 1973, and Bergstrom and Carnes, 1976). Work, done independently of ours in Virginia by J. F. Read and his students has helped clarify, confirm, and extend our environmental conclusions in that direction (Read and Tillman, 1977; Grover and Read, 1978).

Thirty one more or less complete sections, and many other partial sections, of the Middle Ordovician (Llanvirn in part, Llandeilo, and Caradocian) rocks in east Tennessee were studied in the field and more than 4000 thin-sections from the sequence have been analysed. Figure 1 shows the outcrop area with the locality of stops which will be visited during the field excursion. Figure 2 is a fence diagram showing the lithostratigraphic and gross chronostratigraphic relationships in this sequence. Figure 3 shows 2 northwest-to-southeast trending cross-sections, one through the city of Knoxville, Tennessee and the other through the town of Sweetwater, Tennessee. Some of the time-correlation lines derived from our stratigraphic work are shown more clearly on figure 3. The chronostratigraphic relationships shown are based on physical stratigraphy (such things as altered volcanic ash beds, transgressive-regressive cycles, and progradational tongues) as well as biostratigraphic information. The time-framework as well as the paleo-oceanography of the sequence is more fully discussed in Benedict and Walker, 1978. Figures 2 and 3 are restored according to the palinspastic map of Roeder and Witherspoon (1978). The geographic and stratigraphic location of most of the stops which will be made on this field excursion are shown on figures 1, 2, and 3.

The development of the stratigraphic sequence is summarized on the paleobathymetric maps of figure 4 and the sediment maps of figure 5. Each of these series of maps is keyed to the time-lines of figures 2 and 3. When deposition started in the Whiterock-Marmor time (early Middle Ordovician),

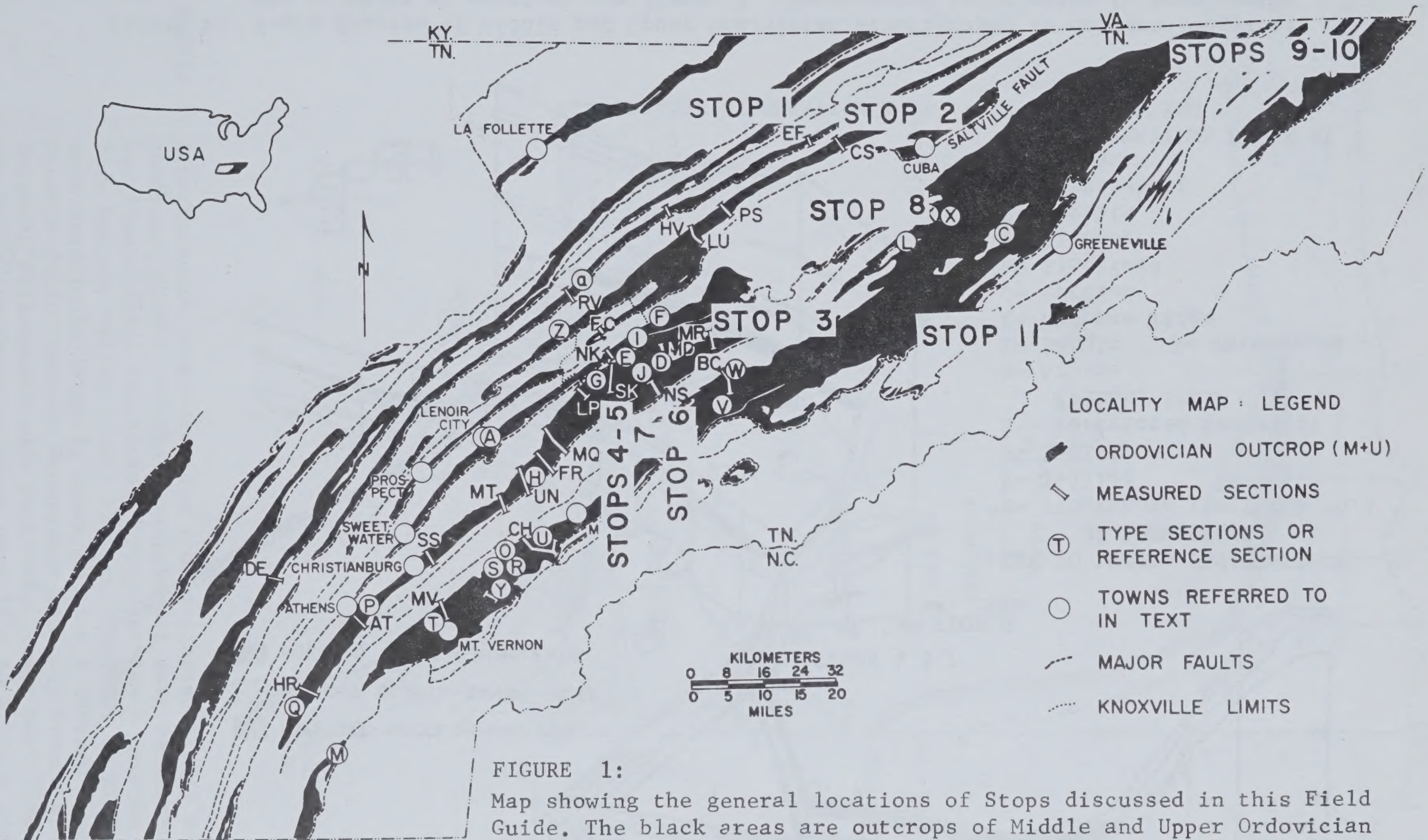


FIGURE 1:

Map showing the general locations of Stops discussed in this Field Guide. The black areas are outcrops of Middle and Upper Ordovician rocks. Location of stratigraphic sections shown on Figures 2 and 3 shown as white bars across outcrop areas and by double letter code.

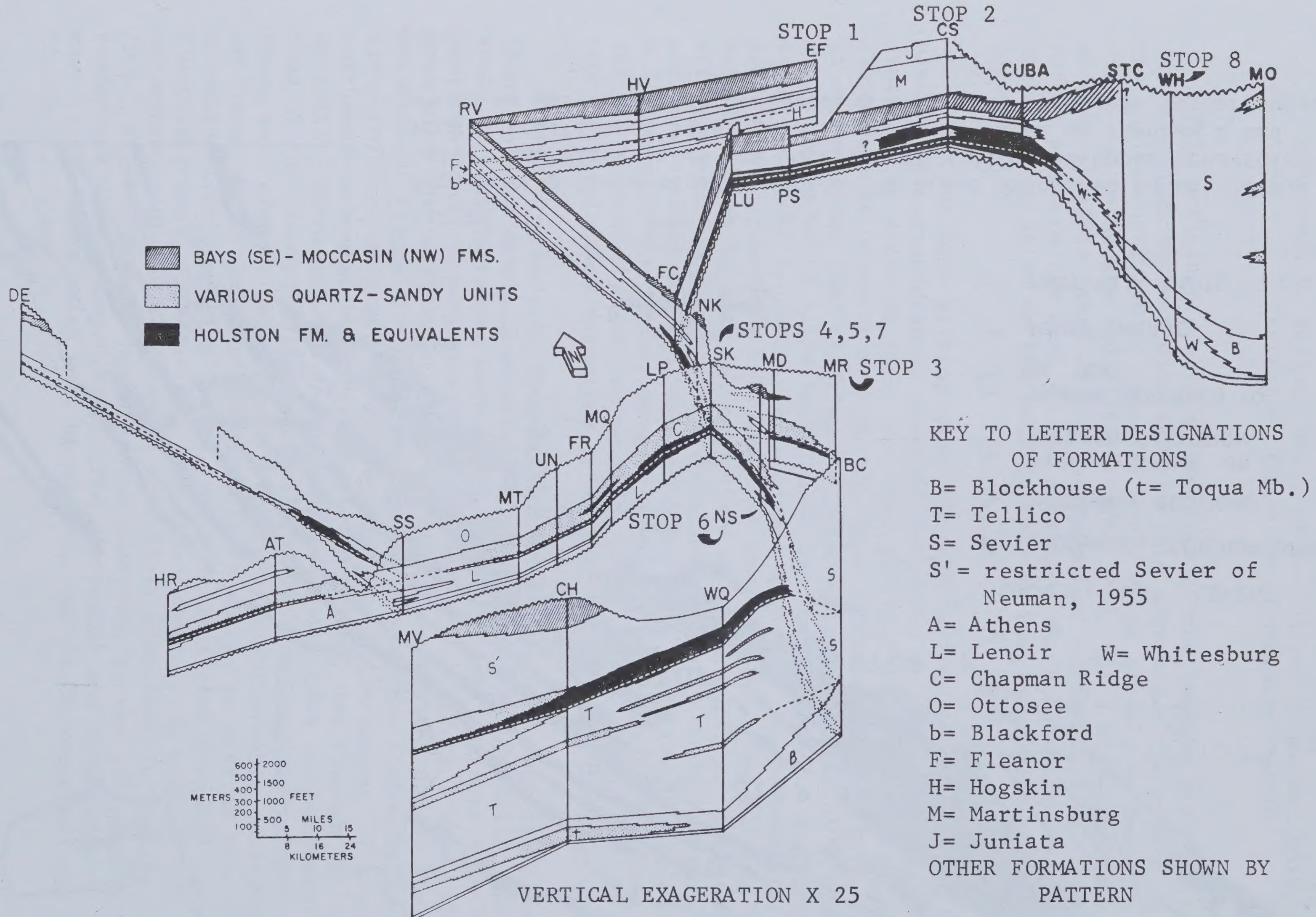


FIGURE 2: Fence diagram of Middle and Upper Ordovician stratigraphy in eastern Tennessee. For location of sections see figure 1. Unpatterned lithologies in more southeasterly sections are mostly shale and siltstone and in more northwesterly sections are various limestone or shaley limestone lithotypes.

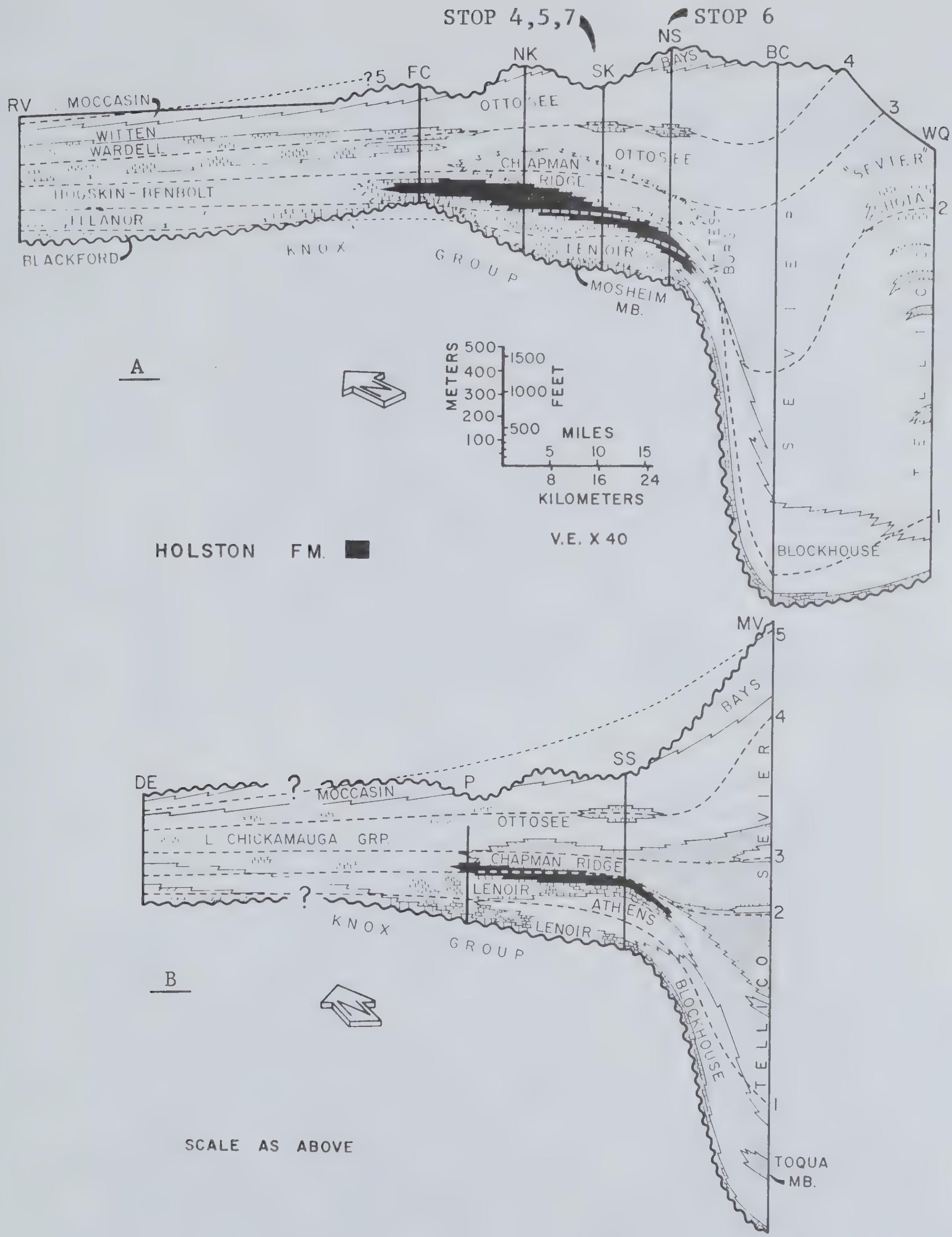
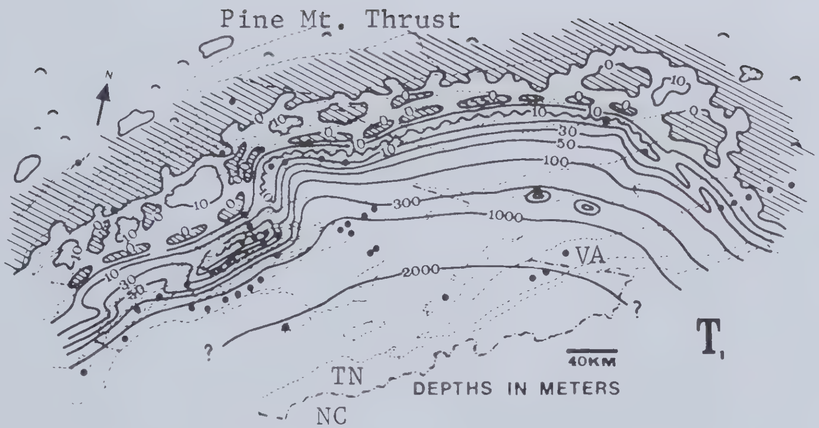
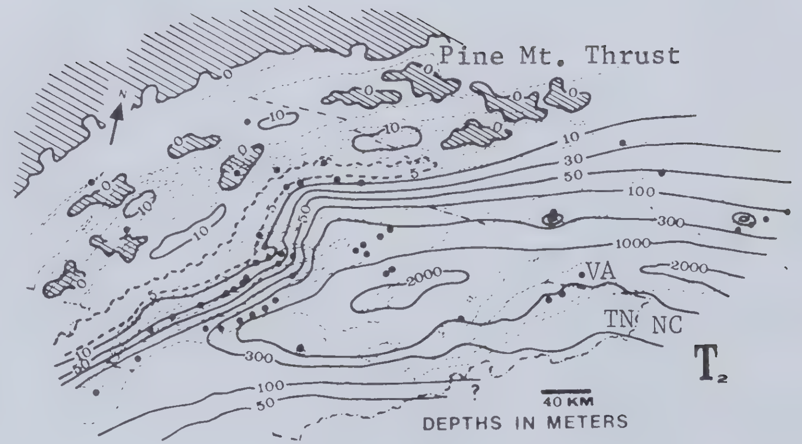


FIGURE 3: Stratigraphic cross-sections from northwest (left) to southeast (right) of the Ordovician of east Tennessee. See figure 1 for localities. Upper section A extends from Raccoon Valley (left) through Knoxville to Wildwood Quadrangle (right). Lower section B extends from Decatur (left) through Sweetwater to Mount Vernon area (right). Palinspastically restored. Lower wavy line is the Knox Unconformity; upper wavy line is present erosion surface.





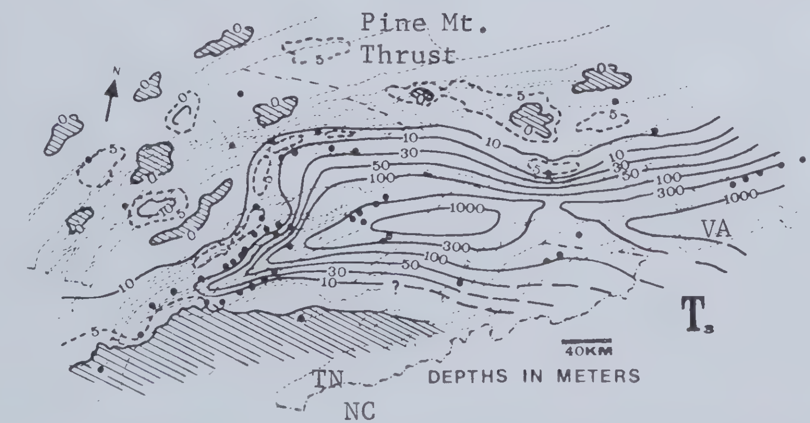
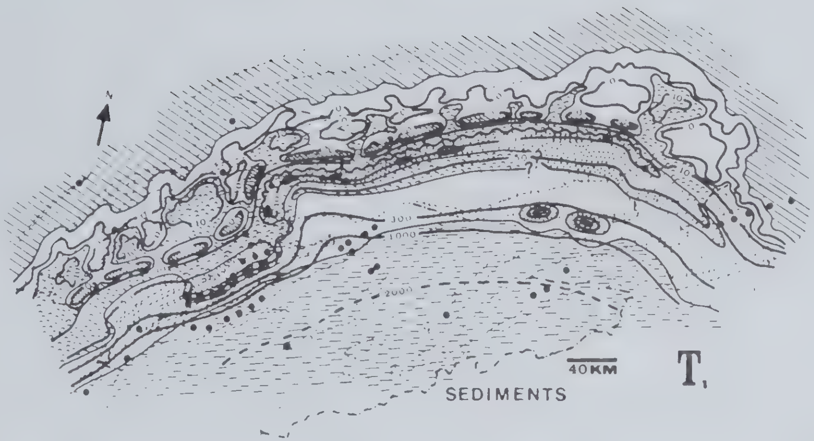
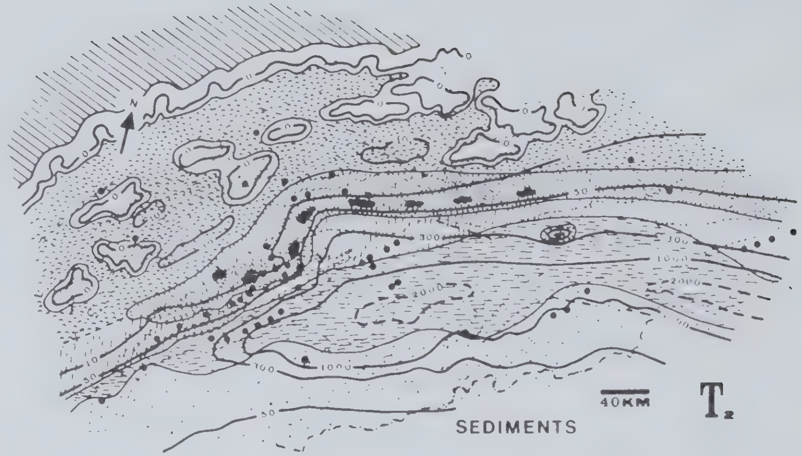


FIGURE 4 (ABOVE AND LEFT): Paleobathymetric maps for times 1, 2, and 3 which correspond to time lines 1, 2, and 3 of figure 3. Base map is the palinspastic map of Roeder and Witherspoon (1978); black dots are data points. Maps cover East Tennessee and Southwest Virginia. Light dashed lines are restored thrust faults.

FIGURE 5 (BELOW): Sediment-type distribution maps for times 1, 2, and 3 which correspond to time-lines 1, 2, and 3 of figure 3. Key to patterns is given to the right of map for T_3.





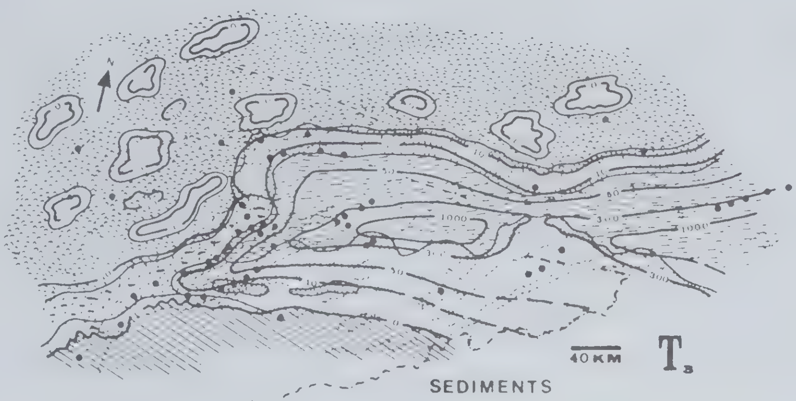


FIGURE 5: <u>KEY TO PATTERNS USED</u>

Exposed and eroding areas..............
Peritidal, desiccated micrites.........
Shallow subtidal, lumpy bedded
  algal/sponge biomicrites.............
Subtidal, pelmatozoan grainstones......
Bryozoan boundstones...................
Slope, interbedded clay shale/limestone.
Basinal, fissile clay shale............
Basinal, ultradistal & distal turbidites
Basinal, distal to proximal turbidites..
Nearshore, subtidal terrigenous sands...
Subtidal, terrigenous sand migrating
  along the former carbonate shelf edge.

overall transgression began from the south and the sea flooded a shelf-like area on which relief was quite low. Over the whole area initial deposition (usually carbonates) took place in the tidal zone or at most a few meters depth (stops 1, 3 and 8). Shortly afterward, however, a major subsidence event (in the region now southeast of the Knoxville area) formed a deep basin bordered northwestward by a shallow carbonate shelf. With the formation of this widely variable bathymetric pattern a much more complex sequence of lithologies began to be deposited. Analysis of these carbonates and terrigenous clastics discloses a facies pattern composed of three parts (see figures 4 and 5): 1) a western carbonate bank bounded on the southeast by a shelf edge skeletal sandbank/reef tract; 2) a deeper-water turbidite basin southeast of the bank edge; and 3) a shallow-water, nearshore area southeast of the basin, near eroding land (the latter most clearly visible in figures 4 and 5 at Time 3).

The bank pattern exposed in the western Valley and Ridge Province consisted of shallow lime-mud or calcarenitic sand flats, separated by tidal mudbanks or skeletal buildups (Stops 1 and 2). The detailed facies pattern in this part of the sequence (Chickamauga Group) is complex in the extreme, with one lithology giving way to another in a few tens to hundreds of meters along strike. This pattern covered at least 70,000 square kilometers. Complex communities in this part of the sequence were dominated by brachiopods, bryozoans, and pelmatozoans, but contained trilobites, snails, ostracodes, bivalved molluscs, sponges, conodonts, and a diverse algal flora (see Moore, 1977, 1979). To the east on the bank, at least for a time during the early development of the pattern, a line of islands of the older Knox Group dolomites (unconformably underlying the Middle Ordovician sequence everywhere) separated the main bank from backreef lagoon sediments now exposed in the central Valley and Ridge. This line of islands is evidenced by a zone of relief, more intense karst development on the Knox surface, zinc mineralization within the underlying Knox, and thinner stratigraphic sequences of the overlying Ordovician units.

Southeast of these Knox Keys, lagoon sediments (Lenoir Formation, Stop 3) indicate four subenvironments. Near the Keys, dismicrites were deposited in a tidal flat complex. This lithology generally is found at or near the base of the Lenoir Formation (this is the Mosheim Member). Offshore from the tidal flats shallow subtidal mudflats characterized by abundant algae and sponges are represented by biomicrites usually stratigraphically just above the Mosheim. Above these in most sections are micrites and biomicrites which have few to no algae and were deposited in a lagoon center, slightly deeper water environment. These deeper lagoon rocks grade southeastward (Stop 6) and southwestward into shale-basin lithologies. Above the lagoon center rocks in most stratigraphic sections, shallow water biomicrites with abundant algae reappear, but with a more diverse fauna containing many transported bryozoa and pelmatozoan debris more characteristic of the overlying Holston Formation. The Holston Formation represents a shelf edge pelmatozoan/bryozoan skeletal sandbank environment in some parts of which bryozoan boundstone masses indicate reef development down-slope from the shelf edge (Stop 4). The several lithologies of the Holston intergrade complexly at a very small scale.

Southeastward from the shelf edge, fine muds were deposited in a deeper basin. Initially, deposition in this basin was very slow and pelagic settling was the main depositional mechanism (Blockhouse Formation, Stop 8, 9) but later distal turbidites showing flame-structures, load casts and other features caused by more rapid deposition (Sevier Formation, Stop 10)became abundant. Separating the bank-edge sequence from the basinal shales, are the slope lithologies of the Whitesburg Formation (Stop 8). The bank sequence is 1000 to 1500 meters thick; the basinal sequence is nearly 3000 meters thick. One outgrowth of our studies of these sequences is a clear understanding of the development and the shape of the carbonate shelf edge. Another important contribution has been improved knowledge of the development and filling of the Sevier Foreland-basin. Several major changes in the trend of the shelf-edge have been the cause of previous interpretational difficulties. The most pronounced change in the shelf-edge trend is the north-south segment between the present locations of Knoxville and Luttrell, Tennessee compared to the generally northeast-southwest trend from Knoxville to the Hiwasee River near Calhoun, Tennessee. The nonlinearity of the shelf-edge, as well as its development through time is clearly shown in the maps of figures 4 and 5. Shanmugam and Walker, 1980, in discussing the development and filling of the Sevier Basin have shown that the subsidence event which formed the basin was quite rapid and had a tectonic rather than a sediment-loading origin. After initial deposition of pelagites in the basin, it was subsequently filled by very fine grained to very coarse grained turbidites derived from both the carbonate shelf to the northwest and from a rising tectonic land to the southeast. We will examine some of these turbidites at Stops 10 and 11.

Southeastward from the basin, a shallow, nearshore shelf depositional pattern developed as the basin filled with terrigenous clastics from the south and southeast. In some areas in the southeasternmost outcrops, submarine-fan, proximal turbidites mark the filling process. These fan deposits include polymict conglomerates with clasts up to one meter in diameter (Stop 10.) As the southeastern side of the basin shallowed, an oolite/patch-reef shoal developed (Chota Formation) which protected a lagoon (lower part of Neuman's "Sevier" Formation, 1956). Stratigraphically upward (and shoreward), sand beach and tidal-flat lithologies were deposited (upper part of Neuman's "Sevier" Formation, 1956, and the Bays Formation.)

As deposition continued, terrigenous sediment swamped the southeastern shelf, filled the basin, and spilled northwestward to kill the bank edge reef (Stop 4). For a time, a metastable balance then existed on the shelf between indigenous carbonate production and arrival of terrigenous clastics from the southeast. At times clastics dominated (Stop 5), and at times when the old basin was temporarily rejuvenated and acted as a sediment trap, carbonate sediments were dominant in the shelf area (Stop 5 and 7). Ultimately, the southeasternmost area became a zone of erosion (indicated by an unconformity between Ordovician and Devonian sediments) and terrigenous clastic deposition came to dominance on the old shelf.

The deposition of the Martinsburg Formation (near the top of western stratigraphic sections) probably represents the development of a foredeep basin in front (west) of the waning Taconic tectonic zone.

The general environmental pattern outlined here for the Middle Ordovician of Tennessee persisted with minor differences into the region of southwestern Virginia (see Read and Tillman, 1977). The maps of figures 5 and 6 are extended into that area based on the work of Read and his co-workers.

Many of the articles in this field guide represent the results of detailed analysis of the outcrops concerned, but some articles are preliminary reports. The reader will doubtless note the differences.

Much of the research reported in the part of this guide pertaining to Tennessee has been supported by National Science Foundation Grants DES-72-01611 and EAR-76-11808 to Kenneth R. Walker. A part of the work and some publication costs were supported by National Science Foundation Grant EAR-7927268 to Walker and Broadhead. We also acknowledge Grants-in-Aid of Research to several participating students from the Geological Society of America and the Society of Sigma Xi. The Don Jones Fund and the Exxon Fund of the Department of Geological Sciences, University of Tennessee aided in the preparation and publication of this guide. The reader should note that all measurements in stop descriptions are given in the Metric System, but the road logs are given in the English System. As noted on the dedication page, this volume is in honor of John Rodgers on the occasion of his "retirement" from Yale University and is cosponsored by the Geological Society of America, the Southeastern section of the Paleontological Society and the University of Tennessee.

NOTES

Fieldtrip Route for Day One

DAY ONE - MIDDLE ORDOVICIAN SHELF DEPOSITS OF THE CHICKAMAUGA GROUP

Introduction

by

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Marine shelf environments ranging from relatively deep subtidal (30-40m.) to intertidal and supratidal are represented by a variety of complex, predominantly carbonate, rock types of the Chickamauga Group. Formational names for many of these units (B.N. Cooper, 1945; Cooper & Prouty, 1943; Cooper, 1956) have suffered from inconsistency of usage and confusion over discrimination of faunal and lithic units. The terminology used here (fig. 6) for shelfal rocks exposed at Evans Ferry and Cedar Springs has been modified from that of earlier workers to reflect the lithologic rather than mixed lithic and biotic distinctions. Most type sections of these formations are in geographic proximity in Northeastern Tennessee and Southwestern Virginia permitting unambiguous lithic correlation as recognized by K.R. Walker and his students.

The vast majority of Middle Ordovician restricted shelf units are presently exposed only in strike belts north and west of the Saltville Fault in Tennessee and Virginia. Coeval rocks exposed south and east of the fault are predominantly shelf edge, slope, and basinal deposits that will be examined in the following days of this field trip. The displacement along the Saltville thrust, which has been estimated to be approximately 35 kilometers in Tennessee (Roeder & Witherspoon, 1978) is reflected not only by the juxtaposition of strike belts containing off-shelf rocks along the fault trace, but also by major faunal changes. At a few localities (eg. at Cuba and Fountain City) these changes in lithotype and biota occur within one fault block.

Major differences in conodonts and several megafaunal groups, especially brachiopods, in correlative Middle Ordovician rocks on either side of the Saltville Fault have been attributed to temporally coexistent faunal provinces (Bergström, 1971, 1973; McLaughlin, 1973; Jaanusson 1973). Conodont faunas of shelf rocks largely resemble characteristic Midcontinent Province faunas, whereas collections from deeper water facies south of the Saltville Fault belong to the North Atlantic Province (Bergström 1973). Controlling factors on distribution of these conodonts probably include a variety of depth-related features, apparently including temperature. Bergström & Carnes (1976) believed that some North Atlantic Province conodonts underwent tropical submergence from shallow water boreal Baltic environments to deeper water subtropical rocks of the Southern Appalachians. However, shallow water carbonates reported from the Baltic are not known to develop in other than tropical environments. Local, fortuitous co-occurrences of key North Atlantic and Midcontinent species has aided understanding of temporal relationships between provincial biozonations.

Brachiopods also exhibit a relatively distinct provincial distribution on opposite sides of the Saltville Fault. McLaughlin (1973) distinguished groups of genera and species characteristic of shelfal units (Chickamaugan Province) and primarily deeper environments south and east of the fault (Blountian Province); several taxa are apparently ubiquitous and aid in correlation. Provinces recognized by McLaughlin probably correspond respectively to the North American Midcontinent - Tunguskan and Scoto-Appalachian faunas described by Jaanusson (1973).

An understanding of these strongly environmentally (especially depth) related "provinces" is a necessary prerequisite to chronostratigraphic classification of Middle Ordovician rocks of the Southern Appalachians. A cursory examination of locations for the type areas of Cooper's (1956) stages (Marmor, Ashby, Porterfield, Wilderness) shows that the type Marmor and Porterfield are both on the south side of the Saltville fault, whereas the type Ashby and Wilderness are on the north side. Thus, the chronostratigraphic relationships of these stages are obscured by a "provincial" or large-scale environmental (shelf vs shelf edge-basin) boundary that strongly affected the distribution of key organi ms, namely the brachiopods. This problem has been highlighted and partly resolved by conodont correlations (Carnes, 1975) that show the base of Cooper's Ashby Stage in its type area to be actually younger than the base of the supposed superjacent Porterfield in its type area. Porterfield - Wilderness correlations remain uncertain and

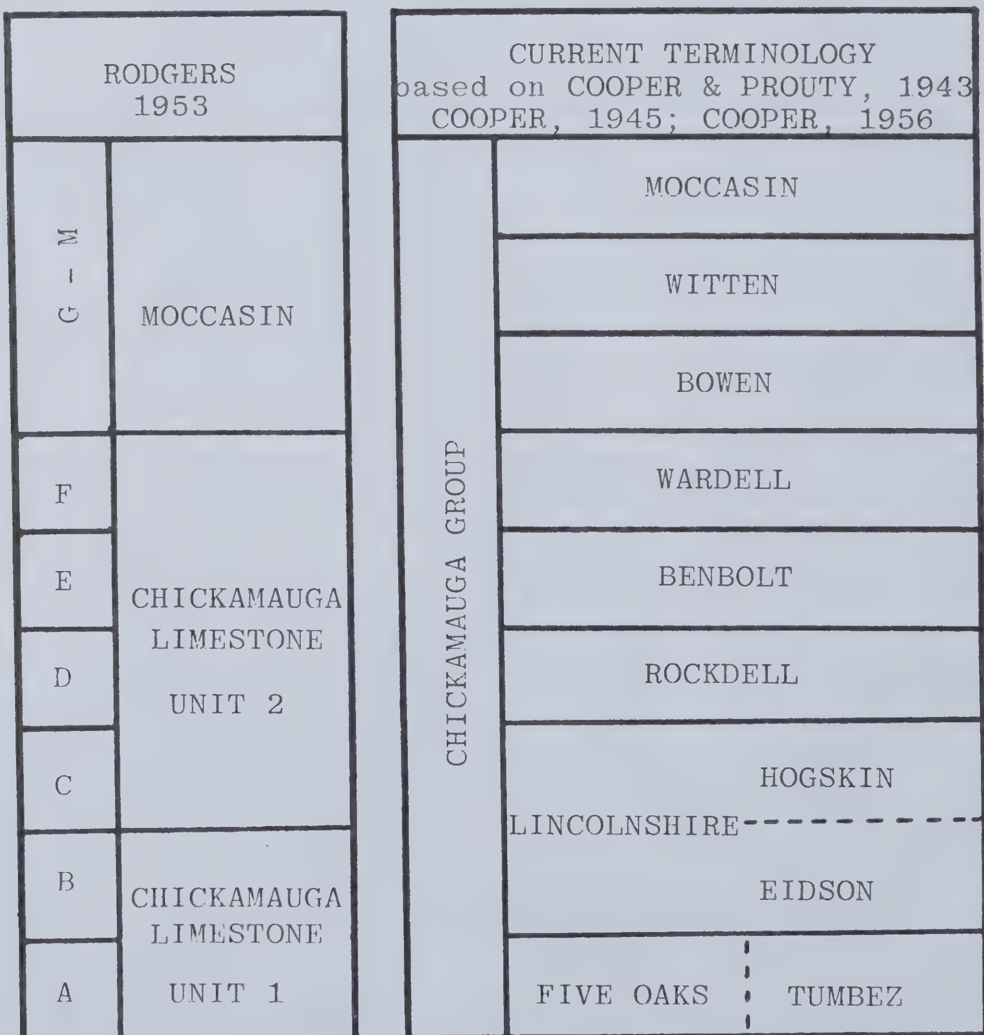


FIGURE 6: Terminology used here (right) compared to Rodgers' (left)

are under study by K.R. Walker and others at the University of Tennessee.

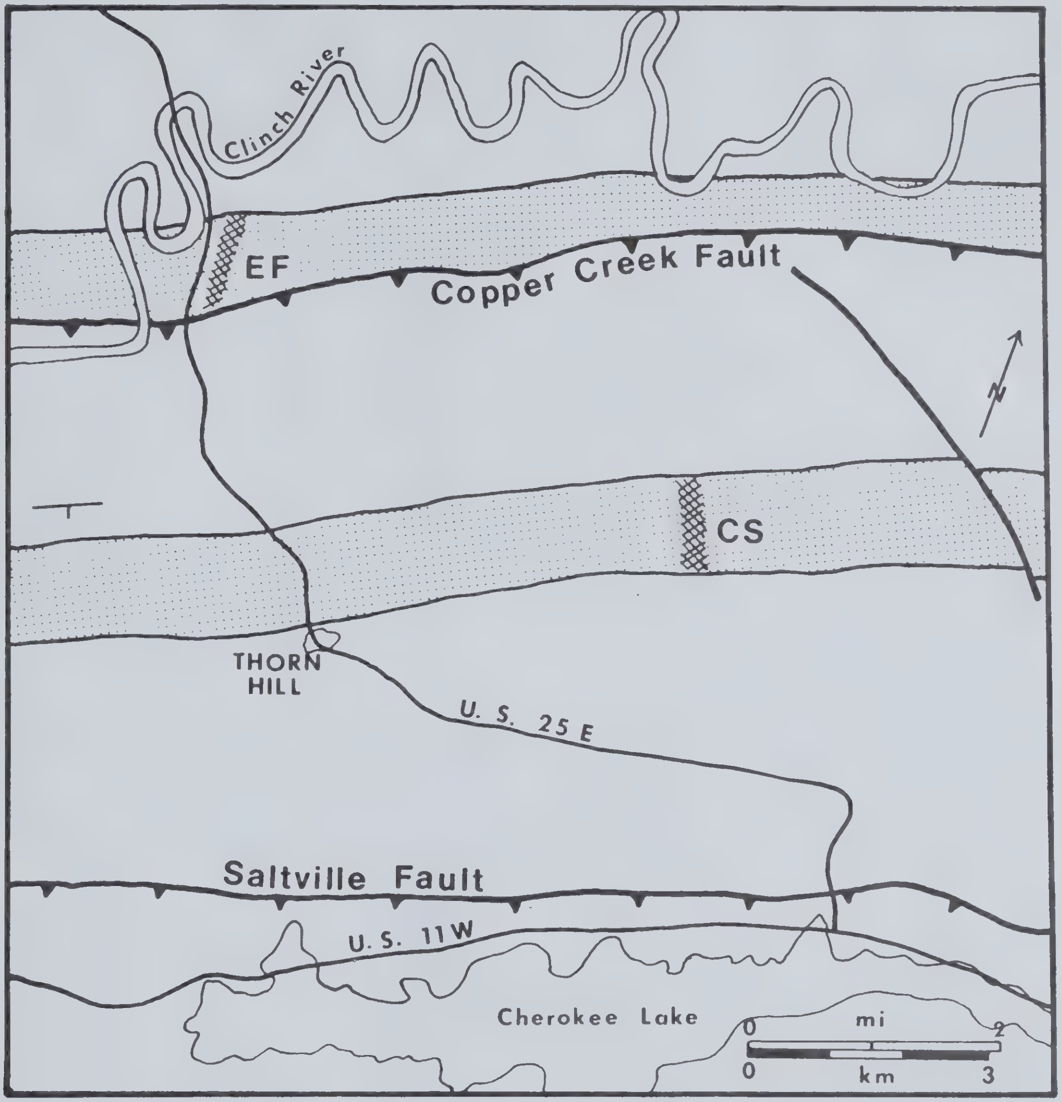


FIGURE 7 General geology of day one stops: Evans Ferry (EF) and Cedar Springs (CS). Stippled areas represent exposures of Middle Ordovician rocks.

The paleobathymetric curves and trilobite distributions for the rocks at the Evans Ferry and Cedar Springs stratigraphic sections (to be examined during Day One are shown in figures 8 and 9.

ROAD LOG

Interval	Cumulative	
0.0	0.0	Board bus and proceed to starting point at intersection of Volunteer Boulivard (16th St.) and Cumberland Avenue. Proceed east on Cumberland.
0.2	0.2	Main Entrance to University of Tennessee. Continue eastward on Cumberland Avenue.

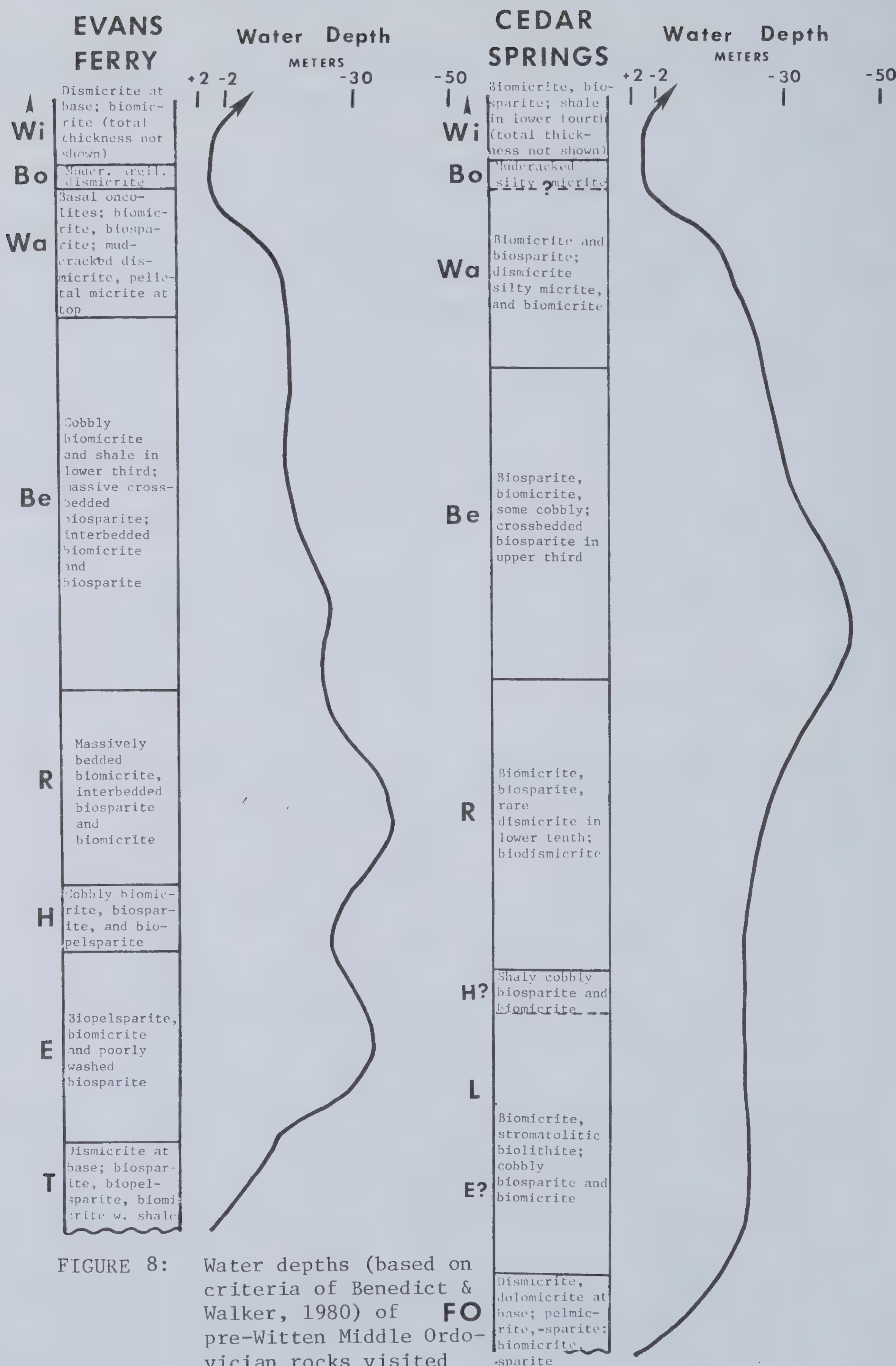
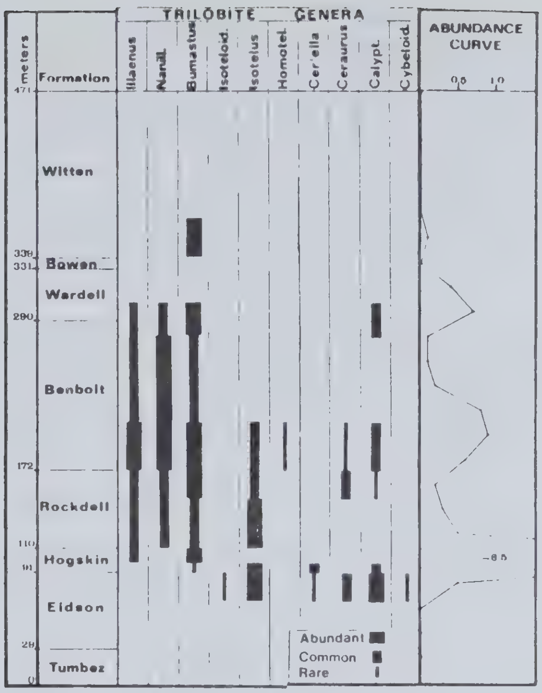


FIGURE 8: Water depths (based on criteria of Benedict & Walker, 1980) of pre-Witten Middle Ordovician rocks visited during day 1.



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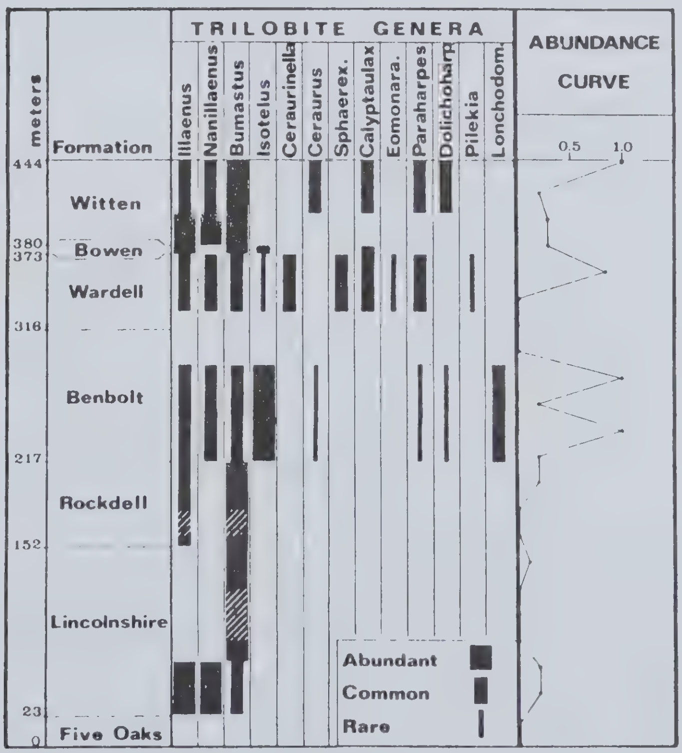

B

FIGURE 9: Trilobite occurrence and relative abundance at (A) Evans Ferry and (B) Cedar Springs (from Maitland, 1979, p. 24, 36). Abundant = > 25% total trilobites; Common = 5% - 25%; Rare = < 5%; diagonal stripes = inferred occurrence. Abundance curve based upon: Total specimens in 20 meter interval ÷ 20 and rounded to the nearest tenth.

0.1	0.3	Fork in road. East bound Cumberland Avenue becomes Main Street. Continue east on Main.
0.3	0.6	Intersection with Henley Street (U.S. 441). Continue east.
0.3	0.9	Intersection with Gay Street. Continue straight ahead (east) and enter Business Loop. Follow signs to I-40.
1.1	2.0	Exit I-40 east (to Asheville).
1.4	3.4	Outcrops of Ottosee Formation (middle Ordovician) at Cherry Street exit. Continue on I-40.
1.5	4.9	Holston Formation on left.
0.6	5.5	Exit I-40 at Rutledge Pike (U.S.11W). Follow 11W north.
7.7	13.2	Divided Highway ends.
5.0	18.2	Knox - Grainger county line.
0.8	19.0	Nolichucky Shale (upper Cambrian) exposed on right.
0.5	19.5	Clinch Mountain on left.
0.5	20.0	Junction with State Road 61. Continue northeast on 11W.
0.4	20.4	Cross splinter of Saltville Fault.
0.3	20.7	Rogersville Shale (middle Cambrian) exposed on left.
1.3	22.0	Rutledge Limestone (middle Cambrian) exposed on left. For the next 12 miles outcrops of Rutledge occur on both sides of road.
9.7	31.7	Enter town of Rutledge.
2.1	33.8	Junction with State Road 92. Continue on 11W.
2.4	36.2	Rogersville Shale on left.
2.0	38.2	Rogersville Shale on left.
2.5	40.7	Bridge over arm of Cherokee Lake.
1.8	42.5	Pumpkin Valley Shale (middle Cambrian) exposed in embayment and along road on left.

1.2	43.7	Rogersville Shale on left.
0.5	44.2	Pumpkin Valley Shale on left.
0.7	44.9	Junction with U.S.25E. Turn left.
0.2	45.1	Rome Formation (lower Cambrian) on right.
0.1	45.2	Saltville Fault.
0.3	45.5	Grainger Formation (Mississippian) on right.
0.3	45.8	Contact of Grainger with Chattanooga Shale (Devonian-Mississippian).
0.2	46.0	Road curves to left and follows strike of Chattanooga.
0.9	46.9	Clinch Sandstone (Silurian) rubble on right.
0.9	47.8	Good exposures of Clinch on right.
1.0	48.8	Cross bedding in Clinch Sandstone.
0.8	49.6	Clinch Mountain Lookout.
0.1	49.7	Silurian-Ordovician contact. Juniata Formation (upper Ordovician) on right. If time permits we will stop here on the return trip for a brief examination of the contact.
0.1	49.8	Martinsburg Shale (upper Ordovician) on left.
1.5	51.3	Moccasin Formation (middle Ordovician) on right.
0.2	51.5	Junction with State Road 131. Town of Thorn Hill. Continue north on 25E.
0.2	51.7	Exposures of Chickamauga Group (middle Ordovician).
0.3	52.0	Quarry in lower Chickamauga on right.
0.1	52.1	Contact with underlying Knox Group (lower Ordovician).
0.3	52.4	Large cut through Knox Group on left and continue on right.
1.1	53.5	Quarry in Maryville Limestone (middle Cambrian) on right.
0.3	53.8	Bridge over arm of Norris Lake.
0.1	53.9	Rome Formation on right.

0.1	54.0	Copper Creek Fault.
0.1	54.1	Moccasin Formation. Note contorted beds on right.
0.3	54.4	Road cut on U.S.25E. Disembark and walk down hill to base of exposure. Watch for traffic!

STOP 1 - EVANS FERRY

by

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A complete 471 meter section of restricted shelf units, from the post Knox unconformity to the base of the Moccasin Formation, is well exposed in roadcuts along both "old" and "new" U.S. Highway 25E 5.9 km northwest of Thorn Hill, Grainger County, Tennessee (fig. 7). The Evans Ferry Section lies within the Hunter Valley Allochthon, (St. Paul Strike Belt of Prouty 1946), bounded on the northwest by the Hunter Valley Fault and on the southeast by the Copper Creek Fault. The second stop today will be in the Copper Creek Allochthon defined by the Copper Creek and Saltville thrusts. The Hunter Valley Allochthon to the southwest contains several excellent exposures currently under study including Hogskin Valley-Lay School, the type area of Cooper's "Ashby Stage" (Ewing, in preparation), Raccoon Valley (Broadhead, in press and in preparation), and Solway Bridge (Weiss, in preparation). The following discussion of the succession at Evans Ferry is based largely upon the petrologic and paleoecologic study by Sickafoose (1979) and observations on trilobite (Maitland, 1979) and echinoderm distribution (Broadhead in preparation).

Post - Knox Unconformity

The unconformable contact of the Chickamauga Group and subjacent Knox Group, commonly poorly exposed in the Southern Appalachians, is apparent just north of "old" U.S.25E at Evans Ferry but will not be visited on this trip. A Mosheim type gray fenestral dismicrite containing chert and dolomite clasts at the base comprises the basal Chickamauga lithotype (lower 0.5 meter of Tumbez Formation) and overlies the Mascot Dolomite of the Knox Group.

Tumbez Formation

The Tumbez Formation, originally described by B.N. Cooper (1945) from south of Tumbez, Russell County, Virginia is poorly exposed in the Evans Ferry area. Four distinct lithic units of the Tumbez reflect the earliest Post-Knox marine transgression at Evans Ferry and represent extremely shallow environments (supra- or intertidal upward to shallowest subtidal). The basal unit (<u>see measured section</u>) is a dismicrite containing chert and dolomite clasts of the underlying Mascot Dolomite. Fenestral fabrics formed from a combination of desiccation, algal activity, and burrowing on a shallow carbonate tidal flat (Logan, et al., 1974; Grover & Read, 1978) populated by euryhaline ostracodes and gastropods.

The more diverse fauna of unit 2 reflects increasing proximity to deeper subtidal, open marine environments. Most allochems are fragmented or abraded and occur in a micrite deficient matrix indicating shoal or strand line agitated environments. Superficial ooids occur throughout unit 2 and micrite envelopes are common. Most allochems (see fig.10) including the alga Hedstroemia were probably transported shoalward, although the abundant peloids may have had a tidal flat source. Similar rocks of unit 3 additionally contain numerous wavy, micritic clay laminae, which represent intertidal or subtidal algally trapped fine sediment. Interlaminated micrite, biopelsparite, biomicrite, and micritic clay laminae characteristic of unit 4 grade upward into the lower Eidson Member of the Lincolnshire Formation. Terrigenous quartz silt becomes increasingly common upward in unit 4. Algally influenced laminae persist from unit 3, but biopelsparite beds reflect storm activity on a lower tidal flat or shallow subtidal bottom.

Eidson Member of Lincolnshire Formation

The Eidson Member was named by Cooper & Cooper (1956) for the commonly cherty lower part of the Lincolnshire Formation, typically exposed at Eidson County, Tennessee. At Evans Ferry, the Eidson is well exposed and includes the transition from the shallow intertidal to subtidal environments of the Tumbez to predominantly subtidal facies of the majority of superjacent units. The basal Eidson (unit 5) resembles the uppermost Tumbez by its cryptalgal clayey micrite laminae and storm-generated abraded biopelsparite laminae. Additionally, it contains thick (10-3 cm.) biopelsparite beds with abundant fragmented and subrounded fossil fragments that may have accumulated as anastomosing channel fills on the carbonate tidal flat (Shinn, et al., 1969).

Unit 6 was deposited in an open marine, subtidal environment indicated by the diverse, apparently indigenous biota exhibiting few signs of abrasion and breakage in a micritic matrix. The algae Girvanella and Hedstroemia (fig. 11) form partial coatings on many fossils but few of these oncoids show evidence of overturning. Distinct, horizontal burrows are common and suggest a firm mud substrate with low water content (Rhoads, 1975). Evidence for sporadic current activity lies in the rare, overturned oncoids and poorly washed biosparite beds common in the middle of unit 6. Diverse carbonate lithotypes characteristic of unit 7 reflect continuation of open marine conditions initiated during unit 6 deposition. Laminated sparsely fossiliferous micrite containing monaxonal sponge spicules (approximately 4%) are interbedded with thin beds of biomicrite, biopelsparite and poorly washed biopelsparite. Undulose black chert beds (5-7 cm. thick) and chert nodules occur conspicuously throughout the unit. The predominantly micrite rich rocks of unit 7 suggest a quiet, level bottom subtidal environment populated by a diverse benthic biota. Thin biosparite beds represent winnowing by occasional storm disturbances or tidal channeling. Elements of the upper Eidson macrobiota, especially trilobites, are commonly conspicuously preserved on the surfaces of chert beds and nodules. Fragments (probably molts) of Calyptaulax sp. (70 of 126 total specimens) and Isotelus sp. (41 specimens) dominate the assemblage (Maitland, 1979).

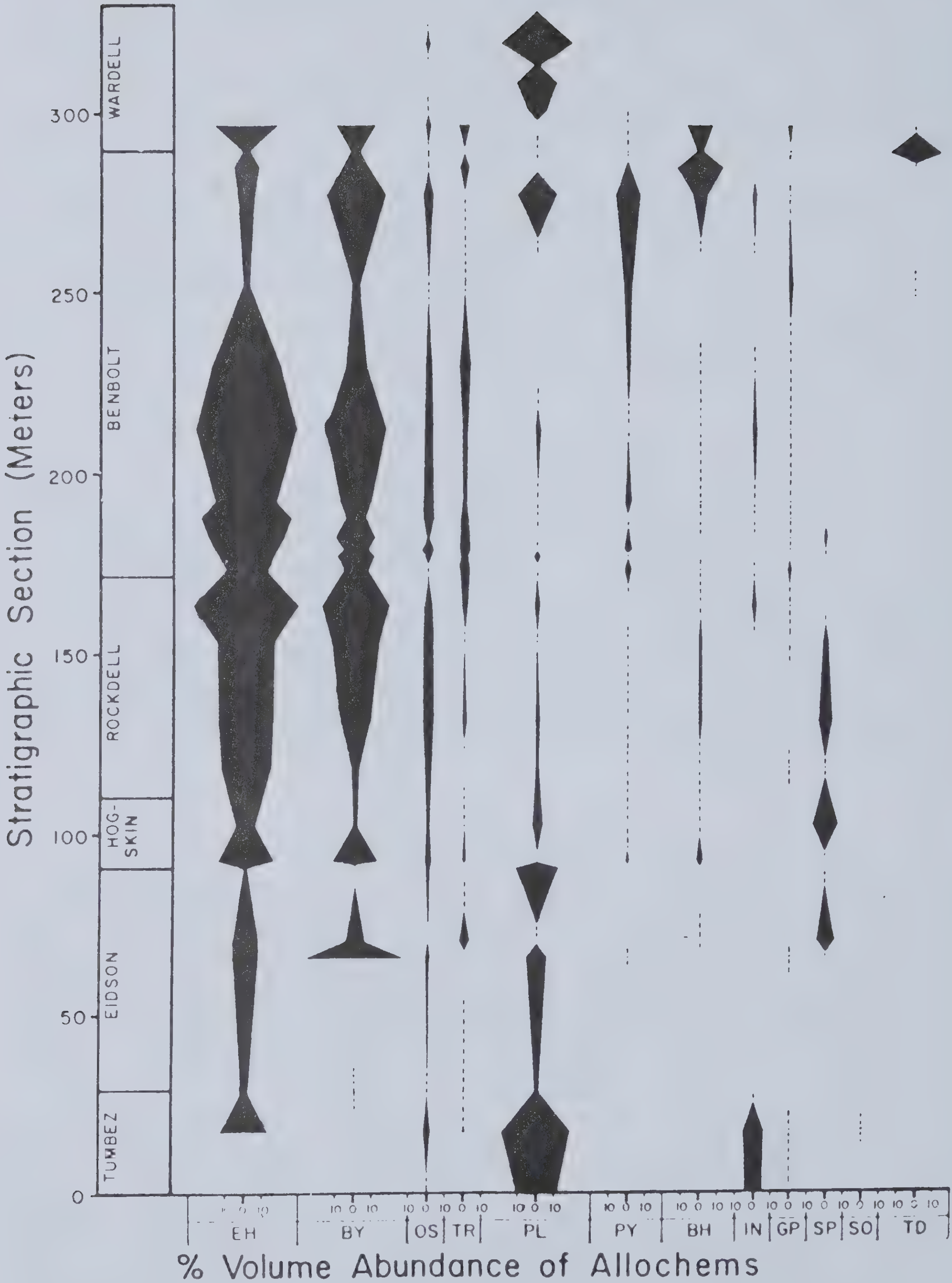

FIGURE 10: Stratigraphic distribution of allochems, excluding algae, at Evans Ferry. Volume percent derived from point counts of thirty 50 x 75 mm thin sections. EH - echinoderms, BY - ectoproct bryozoans, OS - ostracodes, TR - trilobites, PL - peloids, PY - bivalves, BH - brachiopods, IN - intraclasts, GP - gastropods, SP - sponge spicules, SO - superficial ooids, TD - <u>Tetradium</u> sp. (from Sickafoose, 1979, p. 24).

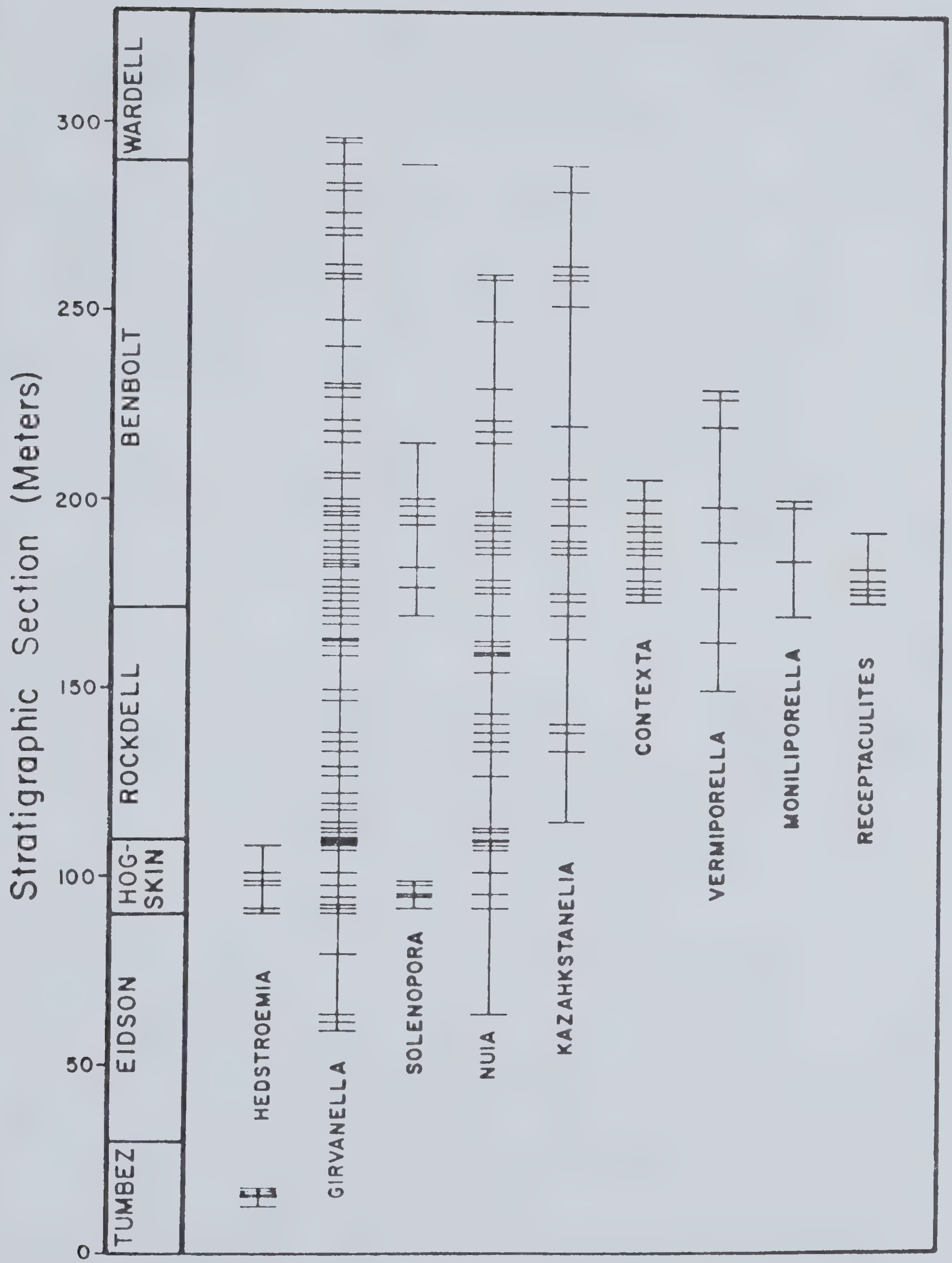

FIGURE 11: Stratigraphic distribution of fossilized algae in Middle Ordovician rocks at Evans Ferry (from Sickafoose, 1979, p. 50). Most genera present are identifiable only in thin section, with the notable exception of Receptaculites, which is a conspicuous megafloral component of the lower Benbolt.

See figure 9 for details of trilobite distribution at Evans Ferry.

Hogskin Member of Lincolnshire Formation

The Hogskin Member was named by Cooper & Cooper (1956) for the upper, shaly and cobbly-weathering limestone of the Lincolnshire Formation. Although Cooper and Cooper did not designate a type section, the Hogskin was named for exposures in Hogskin Valley, approximately 17 km. southwest of Evans Ferry in the same allochthon.

At Evans Ferry the Hogskin comprises two primary lithotypes that are interbedded throughout its 19 meter thickness. The first lithotype, typical of the Hogskin elsewhere, consists of irregular, undulose shale laminae interbedded with biomicrite. This lithology is characterized by cobbly weathering. The second lithotype includes biosparite and biopelsparite containing well rounded and fragmented allochems. Most of the Hogskin Member was probably deposited under low energy shallow subtidal conditions experiencing a sporadic influx of small amounts of terrigenous mud. Thin biosparite and biopelsparite beds represent higher energy storm lags or channel fills containing moderately to well sorted grains that include subrounded fossils and superficial ooids. The alga Girvanella becomes a major constituent (up to 4%) for the first time at Evans Ferry in the lower Hogskin (fig. 12.)

Rockdell Formation

The Rockdell Formation was named by B.N. Copper (1945) for rocks near Elk Garden, Russell County, Virginia that correspond to the Perry and Ward Cove formations elsewhere. Locally the Rockdell exhibits considerable lithic variability and includes red and pink biomicrites and biosparites superficially similar to rocks of the Holston Formation (Stop 4). The Rockdell, however, is characterized by a diverse algal flora that is absent from the Holston (F.C. Breland, pers. comm., 1979).

A moderate to deep subtidal environment was responsible for lower Rockdell (unit 9) deposition. Abundance of micrite and unabraded, indigenous fauna suggest a low energy regime below effective wave base. Sponge remains are relatively common and include both isolated spicules and parts of delicate articulated spicule networks. Girvanella occurs as loosely intertwined tubules, which Moore (1977) believed suggestive of increased water depth. A firm substrate containing abundant nutrients is evidenced by common, distinct, horizontal burrows, although overabundant organic detritus may have caused periodic or local reducing conditions contributing to a sulfurous odor produced upon striking these rocks.

Biosparite and biomicrite characteristic of the upper Rockdell (unit 10) gradationally overly the unit 9 biomicrites. Additionally, a 3 meter thick unit of predominantly unit 10-like biosparite occurs within the lower Rockdell (unit 9). These two units, occurring in vertical succession at Evans Ferry, were probably laterally contiguous subfacies during Rockdell deposition. Biotic constituents of units 9 and 10 are similar, including a diverse algal flora (Contexta, Kazahkstanelia, Girvanella, Nuia, Vermiporella, Moniliporella), but differ primarily in the upward decrease in micrite. Better water circulation which winnowed away micrite may also have introduced abraded algal remains from nearby muddier environments, and precluded local

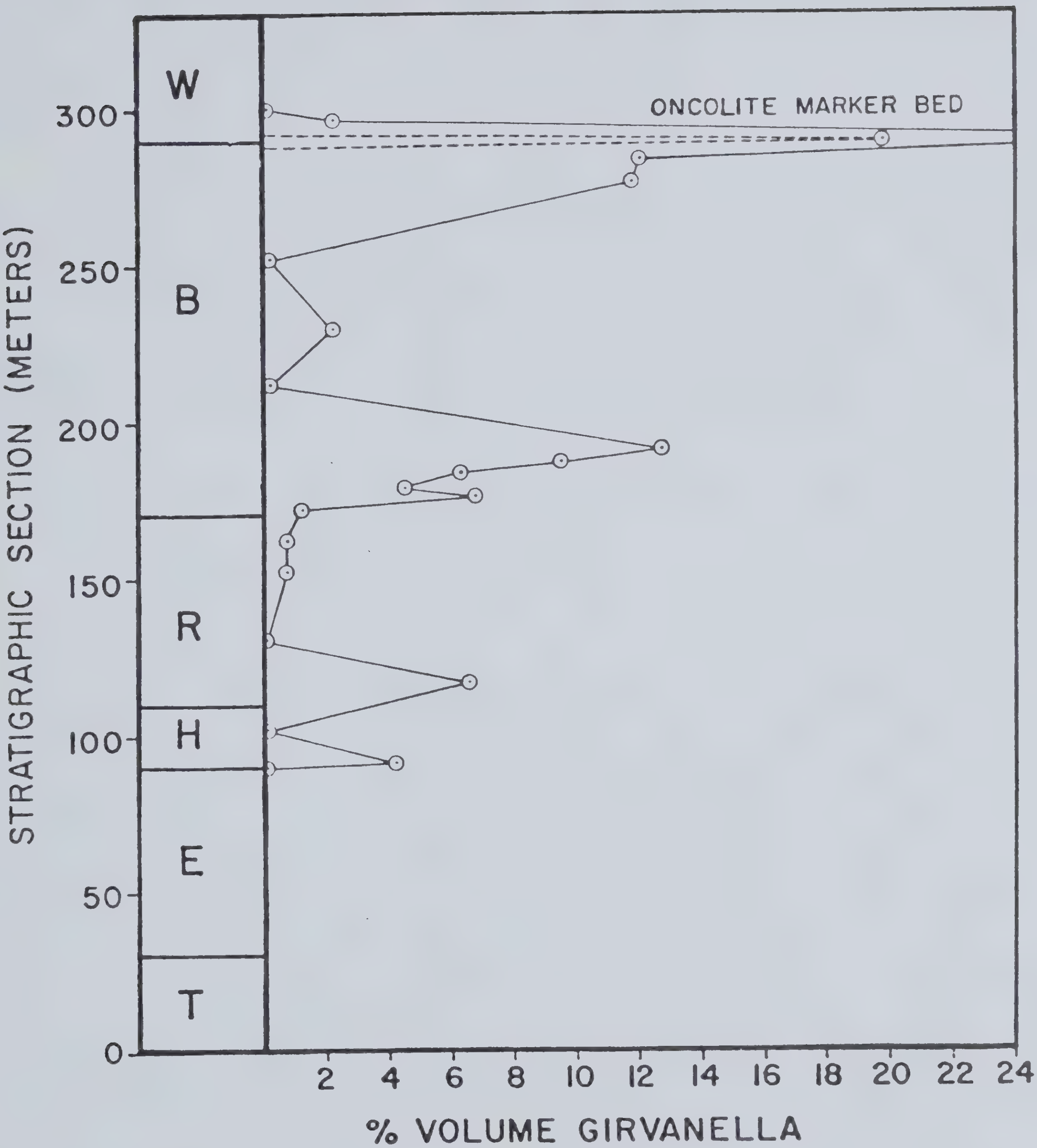

FIGURE 12: Stratigraphic distribution and abundance of Girvanella in Middle Ordovician rocks at Evans Ferry (from Sickafoose, 1979, p. 58). Volume percent was derived from point counts of selected thin sections (individual points on graph). The extreme abundance of Girvanella oncolites in the "oncolite marker bed" provides a convenient operational definition for the boundary between the Benbolt and Wardell formations in the Evans Ferry area.

reducing conditions for there is no fetid odor in unit 10 rocks. The entire Rockdell is characterized by massive bedding and abundant stylolites, predominantly subparallel to bedding planes.

Benbolt Formation

The Benbolt Formation was named by Cooper & Prouty (1943) for rocks south of Benbolt, Tazewell County, Virginia. The two members, Shannondale and Burkes Garden, recognized at the type section have not been identified at Evans Ferry. The Benbolt is a particularly conspicuous and well known unit in the Southern Appalachians. It is extremely fossiliferous, and the typically cobbly-weathering argillaceous limestone beds have yielded an incredibly diverse macrobiota, especially echinoderms, brachiopods, ectoproct bryozoans, trilobites and algae. The shaly nature of the Benbolt permits easy recognition of its lower contact with the more massively bedded Rockdell, but the upper Benbolt tends not to be so distinct from the lower part of the superjacent Wardell Formation.

The lower quarter of the Benbolt at Evans Ferry (Unit 11) exhibits the cobbly weathering shaly biomicrite typically associated with the formation. The diverse biota, including an algal flora comparable to that of the Rockdell but also including Solenopora and Receptaculites, was apparently indigenous to the shallow, quiet subtidal environment. The fine matrix component comprises 43% of the carbonate beds of which 13% is terrigenous clay and 30% micrite commonly neomorphosed to microspar and pseudospar. Clotted textures seen in some thin sections suggest degradation of peloids as a common source of micrite. The argillaceous nature of parts of the Benbolt, such as unit 11 at Evans Ferry, has enhanced collection of the well preserved biota. Abundant brachiopods occur in the Benbolt (Cooper, 1956). Trilobites at Evans Ferry comprise a diverse and abundant element dominated by species of Illaenus, Nanillaenus, and Bumastus, but also including representatives of Isotelus, Homotelus, Ceraurus, and Calyptaulax (Maitland, 1979). Similarly diverse echinoderms recovered at Evans Ferry from the lower Benbolt include crinoids: Palaeocrinus planobasalis, P. avondalensis, Anulocrinus latus, Hybocrinus punctatus, H. punctatocristatus, Carabocrinus micropunctatus, and Paradiabolocrinus sp.; rhombiferans: Regulaecystis pyriformis and Coronocystis angulatus; paracrinoids: Canadocystis tennesseensis (the type locality), Platycystites faberi, and Ulrichocystis eximia; and the parablastoid Meristoschisma fayi. Elsewhere to the southwest in the Hunter Valley Allocthon, the Benbolt trilobite and echinoderm Faunas surpass even the diversity and abundance seen at Evans Ferry.

Unit 11 is succeeded by 16 meters of massive cross-bedded biosparite containing less than 10% micrite (possibly present from peloid degradation.) Allochems are typically fragmented and abraded; micrite envelopes are common. This unit (Member "a" of Harris & Mixon, 1970) exhibits common bidirectional cross stratification suggesting deposition in a tidal channel or tidal bar.

Cross bedded biosparites are overlain by a thick sequence of interbedded biomicrite and biosparite with numerous thick covered intervals (unit 13). Clay layers, lenses, and clasts are ubiquitous in unit 13, and covered intervals may represent especially shaly intervals. Allochems range from scarcely fragmented coarse grains to highly fragmented, abraded, peripherally micritized fossils commonly associated with intraclasts. Algae are comparatively rare and include thin Girvanella coatings and moderately common Vermiporella and Kazahkstanelia respectively characterizing biomicrite beds at 49 meters and 82 meters above the base of the Benbolt. Burrows in these algal biomicrites are poorly defined suggesting a soft mud bottom.

Near the middle of unit 13, a distinct faunal change occurs from the echinoderm - bryozoan rich allochem assemblages of the lower half to a progressively brachiopod dominant assemblage toward the top. The upper 10 meters is characterized by numerous silicified brachiopods, increase in abundance of Girvanella oncolites (Fig. 12) and appearance of quartz silt, possibly derived from a southeast source (Shanmugam & Walker, 1978). Trilobites from the upper Benbolt include only rare specimens of species of Nanillaenus, Illaenus, and Bumastus (Maitland, 1979) and the sparse echinoderm fauna has yielded the eocrinoid Batherocystis appressa and rare cyclocystoid plates. Shallow subtidal conditions of the upper Benbolt suggest a gradual increase in water energy reflected in increasing numbers of oncolites and generally reduced diversity among benthic invertebrates. These conditions prevailed into the overlying Wardell Formation.

Wardell Formation

The Wardell Formation was named by Cooper & Prouty (1943) for a variable succession of limestone typically exposed at Wardell, Virginia. G.A. Cooper (1956) noted that in thrust belts to the northwest the Wardell is commonly separated from the underlying Benbolt by the Gratton Formation, a thick biomicrite and mudcracked dismicrite containing abundant Tetradium sp. At Evans Ferry the base of the Wardell is marked by a distinctive 40 cm thick biomicrite containing abundant (up to 44%) Girvanella oncolites. Although evidence of subaerial exposure, comparable to that of the Gratton, is lacking in the lower Wardell, in situ Tetradium cellulosum colonies are common in the basal 2 meters of the Wardell.

The lower Wardell (unit 14) contains an environmental transition from a shallow subtidal shoaling sequence with oncolites and current baffling Tetradium colonies in a predominantly biomicrite to poorly washed biosparite at the base to a progressively shallower restricted setting at the top. A diverse array of invertebrate fossil allochems occurs in all but the uppermost part of unit 14, and calcareous algae (e.g. Girvanella, Solenopora, Kazahkstanelia) disappear in the upper half. Thin undulose shale beds intercalated with biomicrites contain euhedral dolomite rhombs.

The remaining 30 meters (units 15 and 16) of the Wardell continue the restricted conditions developed in the upper part of unit 14. A variety of interlaminated rock types including dismicrite, pelmicrite, calcareous shale and dolomitic micrite contain little evidence of abundant or diverse life. Skeletal debris is rarely distinguishable although both vertical and horizontal burrows are common. The predominantly muddy sediments of units

15 and 16 were infrequently interrupted by thin layers of abraded skeletal sand probably introduced during storm tides. Identifiable components within these sand layers are predominantly ostracode valves and trilobite debris.

The upper Wardell represents carbonate tidal flat deposition probably controlled by algal mats. Numerous cryptalgal structures include small birdseye fillings, desiccation cracks, fenestral fabric, broken micrite chips, and thicker micrite accumulations on topographic highs. These features compare favorably with those described by Davies (1970) and Logan et al., (1974) in recent sediments of Shark Bay, Australia.

Bowen Formation

The Bowen Formation was named by Cooper & Prouty (1943) from Bowen Cove, Tazewell County, Virginia, for approximately 17 meters of red and brown terrigenous clastics ranging from shale to fine sandstone. At Evans Ferry, the Bowen is only eight meters thick and is considerably more calcareous than at its type section. These rocks are fenestral argillaceous dismicrites and calcareous silty shales, but also exhibit common mudcracks and lack a shelly biota. The Bowen environment was apparently a high intertidal to supratidal setting comparable to conditions during some stages of late Wardell and Tumbez deposition, but with a high rate of fine terrigenous clastic influx.

Witten Formation

Cooper & Prouty (1943) named the Witten Formation for limestones overlying the red, clastic-rich Bowen. The Witten at Evans Ferry is approximately 132 m. thick, but has not been studied in detail petrologically. At Cedar Springs (stop 2) the Witten is much thinner and contains a more diverse and abundant fauna. Most of the lower Witten at Evans Ferry resembles the upper Wardell, but with an upward trend toward increasingly subtidal marine conditions indicated by locally common brachiopods, ectoproct bryozoans, and trilobites. At the top, however, pulses of red clastics, superficially similar to the Bowen, are interbedded with limestones of the Witten. The sequence is capped by red terrigenous clastics of the Moccasin Formation that effectively ended marine deposition here during the Middle Ordovician.

STRATIGRAPHIC SECTION AT EVANS FERRY

Measurement commences at base of section; allochems listed in order of approximate decreasing abundance.

UNIT NO.	UNIT THICK.	CUM. THICK.	DESCRIPTION
			KNOX UNCONFORMITY
1	0.5	0.5	Tumbez Formation - NEXT 4 UNITS: Gray dismicrite with tabular and irregular fenestrae; angular chert pebbles, dolostone intraclasts and dolomite rimmed chert pebbles; disseminated euhedral dolomite (3%); ostracodes, gastropods.

UNIT NO.	UNIT THICK.	CUM. THICK.	DESCRIPTION
2	12.8	13.3	Thick-bedded biosparite and biopelsparite containing subrounded echinoderm debris, peloids, trilobites, bryozoans, ostracodes, intraclasts, superficial ooids, Hedstroemia, gastropods, inarticulate brachiopods; local chertification.
3	4.6	17.9	Interbedded dark orange-brown micritic clay shale laminae and pelsparite/biopelsparite (locally chertified). The latter contain peloids, echinoderm debris, ostracodes, trilobites, gastropods, Hedstroemia; allochems coarsening upward. Upper 0.5m with micritized skeletal debris, abraded tabular intraclasts, superficial ooids.
4	11.0	28.9	Laminated micrite interbedded with biopelsparite, biomicrite, and orange-brown micritic clay laminae containing abraded echinoderm debris, peloids, ostracodes, trilobites. Fine quartz sand and silt, concentrated in biopelsparite, top of unit. TOTAL TUMBEZ FORMATION=28.9 METERS.
5	27.5	56.4	Eidson member of Lincolnshire Formation - NEXT 3 UNITS: Wavy laminated alternating clayey micrite and biopelsparite with thick (10-30 cm) biopelsparite beds, of echinoderm debris, peloids, ostracodes, trilobites, bryozoans, brachiopods.
6	9.4	65.8	Biomicrite with poorly washed biosparite more common toward top of unit, containing echinoderm debris, bryozoans, brachiopods, ostracodes, trilobites, gastropods, and bivalves. Girvanella and Hedstroemia partial coatings on tabular fossils.
7	24.2	90.0	Laminated biomicrite and biopelsparite, containing echinoderm debris, bryozoans, sponge spicules, trilobites, brachiopods, rare Girvanella. Locally replaced by bedded and nodular black chert. TOTAL EIDSON MEMBER = 61.1 METERS.
8	19.0	109.0	Hogskin Member of Lincolnshire Formation - NEXT 1 UNIT: Interbedded 1-6m intervals of cobbly weathering biomicrite and 0.4 - 1m massively bedded biosparite and biopelsparite. Cobbly biomicrites contain wavy shale laminae 1 - 3cm thick and echinoderm debris, bryozoans, brachiopods, ostracodes, trilobites, bivalves, gastropods; neomorphosed micrite common. Thin Girvanella coatings, Solenopora, Hedstroemia, Nuia are minor algal constituents. Biosparite and biopelsparite contain echinoderm debris, bryozoans, trilobites, ostracodes, gastropods, peloids, bivalves,

UNIT NO.	UNIT THICK.	CUM. THICK.	DESCRIPTION
			superficial ooids, brachiopods, algae: Girvanella, Solenopora, Hestroemia. TOTAL HOGSKIN MEMBER = 19.0 METERS. TOTAL LINCOLNSHIRE FORMATION = 80.1 METERS
9	49.6	158.6	Rockdell Formation - NEXT 2 UNITS: Massively bedded, irregularly stylolitic argillaceous biomicrite with echinoderm debris, bryozoans, sponges and spicules, ostracodes, trilobites, gastropods, bivalves, brachiopods, algae: Girvanella, Nuia, Kazahkstanelia. Horizontal burrows common.
10	12.0	170.6	Interbedded biosparite and biomicrite containing abraded allochems: echinoderm debris, bryozoans, algae (Contexta, Kazahkstanelia, Girvanella, Nuia, Vermiporella, Moniliporella), ostracodes, trilobites, peloids. Horizontal burrows only in lower 4 meters. TOTAL ROCKDELL FORMATION = 61.6 METERS.
11	30.0	200.6	Benbolt Formation - NEXT 3 UNITS: Interbedded cobbly weathering biomicrite and shale with decreasing thickness (3 to 1-2 cm) of shale beds and increased thickness (6 to 10 cm) of limestone beds from lower half to upper half of unit. Allochems include echinoderm debris, bryozoans, algae (Girvanella, Contexta, Nuia, Solenopora, Kazahkstanelia, Moniliporella, Vermiporella), trilobites, ostracodes, bivalves, pellets, gastropods, sponges.
12	16.0	216.6	Massive, cross-bedded biosparite with echinoderm debris, bryozoans, ostracodes, trilobites, pellets, intraclasts, brachiopods, gastropods, sponge fragments, algae (Contexta, Kazahkstanelia, Girvanella).
13	71.0	287.6	Interbedded biomicrite with rare biosparite containing echinoderm debris, bryozoans, brachiopods, Girvanella, bivalves, trilobites, ostracodes, pellets, intraclasts. Girvanella coatings rare in lower part, oncolites restricted to upper 13 m. Clay layers, lenses, clasts ubiquitous; covered intervals, 0.5 - 7m thick throughout the unit probably represent weathered clay shale units. Quartz silt present in upper 10m. Distinctive beds include a Vermiporella (7%) biomicrite at 219 meters above base of section and a Kazahkstanelia (7.5%) biomicrite at 252 meters. TOTAL BENBOLT FORMATION = 117.0 METERS.

UNIT NO.	UNIT THICK.	CUM. THICK.	DESCRIPTION
14	10.0	297.6	Wardell Formation - NEXT 3 UNITS: Biomicrite and poorly washed biosparite with intercalated dolomitic calcareous shale laminae. Allochems include echinoderm debris, bryozoans, brachiopods, trilobites, gastropods, ostracodes, bivalves. *Tetradium* colonies common in lower 2 meters; *Girvanella* oncolites common (15%) in lower 5 meters but abundant (44%) at the base.
15	21.0	318.6	Interlaminated, fenestral dolomitic calcareous shale, lenticular pelsparite, and dolomitic micrite commonly burrowed with extremely rare ostracodes (imbricate in one sample) and trilobites.
16	9.0	327.6	Mudcracked, laminated dismicrite and pelletal micrite with thin clay-rich micrite laminae. Lower part of unit with interbedded Unit 15 and Unit 16 lithotypes. Fenestral fabric common. TOTAL WARDELL FORMATION = 40.0 METERS.
17	8.0	335.6	Bowen Formation - NEXT 1 UNIT: Maroon to greenish gray, mudcracked, fenestral, argillaceous dismicrite to calcareous silty shale. TOTAL BOWEN FORMATION = 8.0 METERS.
18	132.0	467.6	Witten Formation (from Maitland, 1979) - NEXT 1 UNIT: Burrowed dismicrite with only small argillaceous component and few mudcracks becoming more thickly bedded biomicrite with brachiopods and ostracodes toward top. Upper 2-3 meters interbedded with lower reddish brown clastic rocks of Moccasin Formation. END SECTION.

ROAD LOG

Interval	Cumulative	
	54.4	Reboard bus at end of outcrop and retrace route toward Thorn Hill.
2.9	57.3	Thorn Hill. Junction of Tennessee Route 131. Turn left (northeast). This road runs generally along strike (approximately N 60^{o}E). Exposures of Moccasin are seen on both sides of road.
1.0	58.3	Road to left leads to the New Jersey Zinc "Idol" Mine. Mining is in the Knox Group just below the unconformity separating the Lower and Middle Ordovician.
0.1	58.4	Contorted Moccasin beds on right at entrance of paved road.

1.6	60.0	Turn left on Cedar Springs Church road.
0.2	60.2	Fork in road, keep left.
0.4	60.6	STOP 2. Cedar Springs Church. Park and disembark, After studying STOP 2, we will reboard the bus at the southeast end of the section (at the intersection of the church road and the main road).

STOP 2 - CEDAR SPRINGS

by

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Restricted shelf units at Stop 2 comprise a complete, approximately 425 meter thick, sequence from the post Knox unconformity to the base of the Moccasin Formation. The section is well exposed along Cedar Springs Creek and in field on either side of Cedar Springs Church road, approximately 4.8 km northeast of Thorn Hill, Grainger County, Tennessee. The Cedar Springs section lies within the Copper Creek Allochthon bounded on the northwest by the Copper Creek Fault and bounded on the southeast by the Saltville Fault. Cedar Springs is presently 7 km. east-southeast of Evans Ferry, but palinspastic reconstruction (Roeder & Witherspoon, 1978) and consideration of paleoslope (Ruppel, 1979, fig. 3.2) show it to have been approximately 17 km. basinward of Evans Ferry during the Middle Ordovician. Detailed petrologic analysis (Ruppel, 1979) of Cedar Springs rocks and consideration of the relationship of this section to regional patterns form the primary base for the following discussion.

STOP 2A

The base (units 1-2) of the Middle Ordovician section at Cedar Springs is a thin (1.5 meter) sequence of greenish gray dismicrite and dolomicrite containing rounded chert clasts from the underlying Knox Group, and is typical of the Blackford Member of the Five Oaks Formation. The Blackford has been reported to have a thickness as great as 60 meters (Rodgers & Kent, 1948), but subsequent restudy of the unit has distinguished the upper bedded chert as a different formation (Cooper, 1956). Nevertheless, the unusual thinness of the Blackford here suggests a topographic high on the eroding Knox karst surface in the Cedar Springs area.

The remainder of the Five Oaks was deposited under restricted tidal flat conditions and contains a sparse fauna of ostracodes, trilobite debris, sponge spicules, and gastropods (e.g., Loxoplocus, Lophospira). Laminae, some possibly cryptalgal, are common throughout the upper part of the Five Oaks (units 2-19), but the only skeletonized algae are specimens of Solenopora occurring the top few meters. Rocks range from pelmicrite and pelsparite to biomicrite and biosparite and contain birdeyes and disseminated dolomite rhombs (see fig. 13).

Retrace path to church and continue into field west of church road.

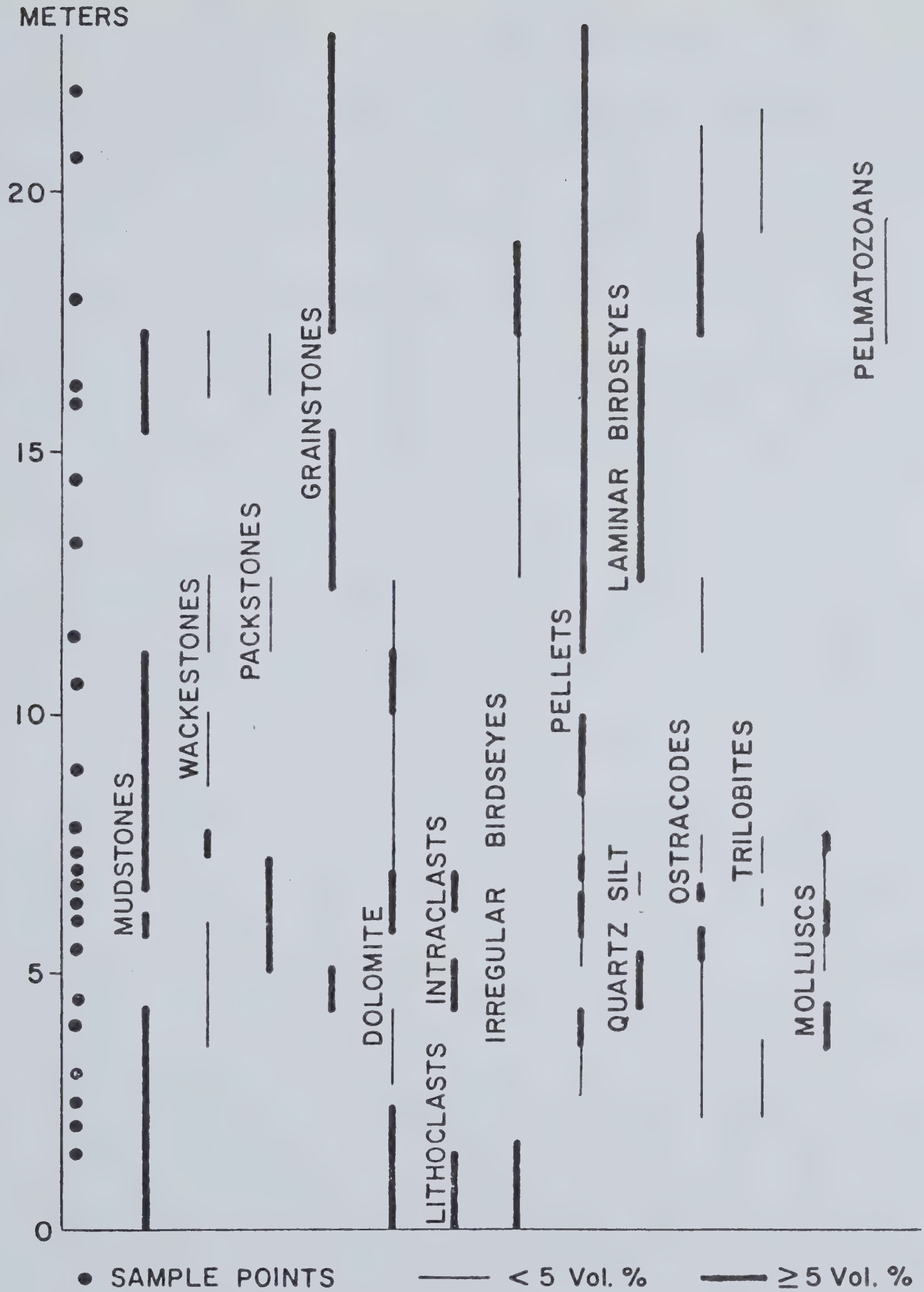

FIGURE 13 Distribution of lithic, biotic, and sedimentologic features in the Five Oaks Formation at Cedar Springs (from Ruppel, 1979, p. 65). See figure 9 for trilobite distribution.

STOP 2B

Lincolnshire Formation

The two distinctive members of the Lincolnshire seen at Evans Ferry (stop 1) are not easily definable at Cedar Springs. The lower 43.5 meters (units 20-27) are generally similar to the lower Eidson Member at Evans Ferry, but the bedded and nodular chert at the top of the member is notably absent. The upper 15 meters of the Lincolnshire do have the shaly, cobbly-weathering appearance comparable to the 19 meters of the Hogskin Member at Evans Ferry.

The Lincolnshire, which is approximately 98 meters thick at this locality, is gradational from the underlying rocks, and marked near the base (field unit 21) by a prominent zone of well developed algal stromatolites of the LLH-SH type (Logan et al., 1964). It is, thus, environmentally equivalent at the base to the Lincolnshire at Evans Ferry - a short transition from restricted tidal flat to shallow subtidal, more open marine conditions, which were still influenced by tidal forces.

This part of the Cedar Springs section (field units 20-35) consists of alternating units of nodular weathering skeletal calcarenites grossly similar to the Lenoir Formation (see Stop 3), and massive, sometimes cross bedded, gray to pink skeletal calcarenites not unlike the skeletal sands of the Holston Formation (see Stop 4). These two lithotypes are not markedly different when studied in thin section. They are both predominantly biosparites, and contain similar fossils including bryozoans (chiefly ramose), pelmatozoan debris, algae (Solenopora, Girvanella oncolites, Hedstroemia, and occasional Nuia), and ostracode and trilobite debris. The more massive limestones do contain a higher proportion of bryozoans and pelmatozoans, and algally coated grains (Girvanella). Extremely large (up to 8 cm.) oncolites can be observed about 67 meters from the base of this interval (field unit 27). The chief difference between these two lithotypes, however, seems to be the amount of clay present, and the degree of stylolitization; the nodular rocks show greater amounts of each. Several workers (e.g. Wilson, 1969) have suggested that nodular bedding is produced by soft sediment deformation (i.e. differential compaction) of subjacent clay and carbonate layers. Pressure solution has undoubtedly had a major influence on the formation of this irregular bedding as well. See Logan and Semeniuk (1976) for a comprehensive treatment of pressure solution phenomena.

The Lincolnshire is interpreted as having been deposited in a lower intertidal to shallow subtidal carbonate flat. Stromatolites near the base are typical of those believed by Logan et al. (1964) to be indicative of lower intertidal to protected shallow subtidal environments. The massive calcarenites, which contain abundant oncolites and very little clay or mud, formed as higher energy channel deposits of winnowed and reworked sediment from the lower energy, more protected, tidal flat (nodular limestones).

Rockdell Formation

The Rockdell Formation at Cedar Springs (field units 36-44) is much thicker (93.5 meters) than at Evans Ferry (61.6 meters). Bryozoan boundstone masses occur sporadically throughout the Rockdell from units 38 to 44 and represent periodic surface stabilization in what were otherwise a complex series of mud and skeletal sand banks. Biomicrite and biosparite beds dominate the Rockdell lithotypes and contain a diverse biota including a variety of algae (Contexta, ?Vermiporella, ?Spongiostroma). Cryptostome and trepostome bryozoans and echinoderm debris are volumetrically the most important distinguishable biotic elements. Ostracodes and trilobites have been observed primarily in thin section, although Maitland (1979) recovered rare fragmentary specimens of the trilobites Bumastus and Illaenus.

A distinct parallel can be drawn between the Rockdell at Cedar Springs and Holocene sediments of southern Florida, such as banks and "keys" of Florida Bay. Encrusting bryozoans and algae (particularly Spongiostroma) in the Middle Ordovician were analogous to many of the marine grasses (e.g. Thalassia) of Florida Bay in trapping and binding loose calcareous sediment into a series of anastomosing mud banks.

Skeletal grainstones in the Rockdell bear a superficial resemblance to those of the Holston Formation, which will be visited tomorrow (Stops 3, 4). This is especially true in the upper Rockdell (field units 40-44) where some beds tend to have a red to reddish brown coloration. The Holston, however, was a generally deeper water buildup that lacked the algal flora seen in the Rockdell.

Benbolt Formation

This sequence (field units 45-53) records the onset of a major environmental change, which later culminates in the terrigenous clastic deposits of the Moccasin and Martinsburg Formations. The nodular bedding and numerous covered intervals in the lower part of the Benbolt (units 45-52) are consistent with an increased influx of terrigenous sediment.

At the base, a sharp change in biotic content occurs. Brachiopods, such as species of Leptellina and Mimella, become widespread for the first time. They are commonly silicified and readily weather out on the outcrop surface. Trilobite diversity is quite high; common forms are illaenids (Illaenus, Nanillaenus, Bumastus) and Isotelus. Other genera present, noted by Maitland (1979), are Ceraurus, Lonchodomas, Paraharpes and Dolichoharpes. Echinoderms appear to be neither as diverse nor as abundant as at Evans Ferry, and include the rhombiferan Coronocystis, diploporitan plates (?Eumorphocystis), the small crinoid Apodasmocrinus, archaeocrinid or diabolocrinid debris, and unidentified columnals. Sponges, cephalopods, gastropods and ostracodes are also well represented. With the exception of Receptaculites, which first appears and is locally abundant in the Benbolt, calcareous algae have disappeared and are not present subsequently until approximately 157 meters higher in the Wardell (unit 58). In thin section, the Benbolt exhibits a complex assemblage of biosparites with occasional trilobite dominated biomicrite beds (fig. 14).

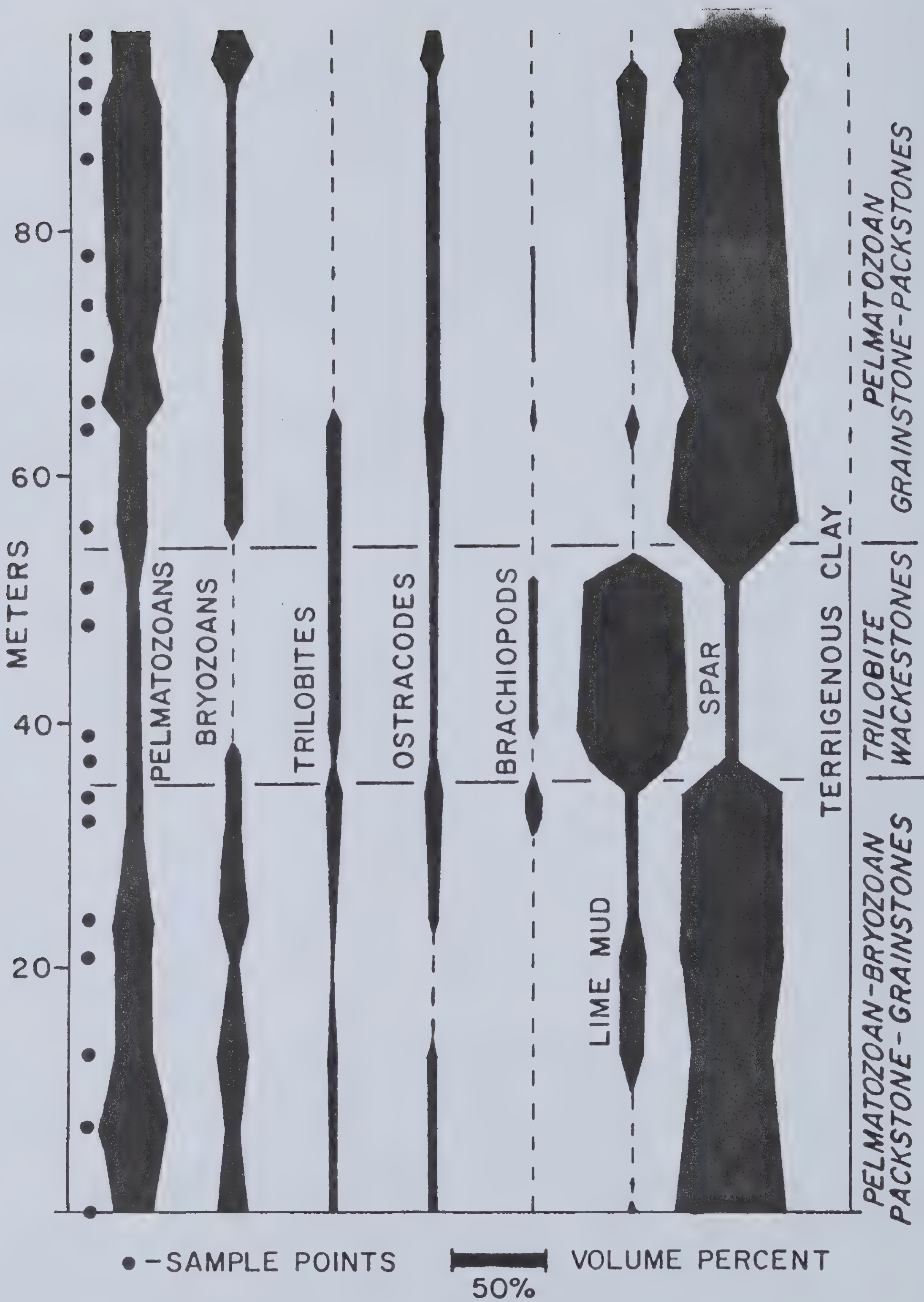

FIGURE 14 Essential constituents of the three basic lithofacies of the Benbolt Formation at Cedar Springs (from Ruppel, 1979, p. 82).

This part of the Benbolt at Cedar Springs was probably deposited in a somewhat deeper, more turbid regime than the Rockdell. Although biotic diversity is still high, calcareous algae have all but disappeared in contrast to their abundance and diversity at Evans Ferry. Because of the abundance of terrigenous sediment, only a slight deepening may have occured in conjunction with increased turbidity to apparently limit the effective penetration of sunlight. Likewise, development of a seaward barrier preventing winnowing waves may have "ponded" the clay-rich sediments shoreward from the major zone of effective wave action.

Holston-like echinoderm-bryozoan biomicrite and biosparite dominate the upper 31 meters of the Benbolt. Reflecting a return to shoaling conditions similar to those earlier encountered in the Rockdell, but lacking an algal flora. Upper Benbolt skeletal sands may have been deposited as migrating sand banks that restricted effective wave base seaward of the area where more terrigenous-rich sediments accumulated. Later, sand banks probably migrated over back-bank sediments as shoaling increased.

Wardell Formation

Deposition of the Wardell Formation represents increasingly shallow, sporadically terrigenous clastic rich environments with a progressively limited biota. The lower Wardell (unit 54) contains a diverse fauna including rather diverse and abundant echinoderms (e.g. Diabolocrinus, Hybocrinus, Acolocrinus, Apodasmocrinus, Meristoschisma) plus ectoprocts, brachiopods, trilobites, and sponges. The alga Receptaculites is also common. Overlying silty micrites and dismicrites indicate progressive shallowing and contain few recognizable fossils. Covered intervals probably represent fine-grained clastic rich intervals that are less resistant to erosion.

Near the top (units 57-58), the Wardell possesses a sparse fauna commonly associated with biosparite beds of possible storm tide origin. Although clay content is variable, a notable increase occurs in the upper two meters, a precursor to the rapidly deposited terrigenous clastics of the superjacent Bowen Formation.

Bowen Formation

Only approximately 5 meters of the Bowen are actually exposed at Cedar Springs. These rocks overlie a 5.5 meter covered interval above the highest exposed Wardell (unit 58) that very likely represents deeply eroded less resistant clastics of the lower Bowen. The exposed calcareous siltstone and silty micrite of the Bowen lack a shelly fauna and contain a few burrows and mudcracks characteristic of intertidal deposition.

Witten Formation

At Cedar Springs, the Witten Formation represents a return to somewhat less restricted, terrigenous-dominated conditions. Although the lowermost Witten (unit 60) still contains an abundance of shale, it ex-

CONSTITUENT	FIVE OAKS	LINCOLNSHIRE	ROCKDELL	HOLSTON	BENBOLT	WARDELL	BOWEN	WITTEN	MOCCASIN
Dolomite	C	–	–	–	–	–	–	–	–
Spar	–	C–A	C–A	R–C	R–C	R–C	R	R–A	R
Birdseyes	C–A	–	R	–	–	–	–	–	C–A
Micrite	A	R	R–C	R–C	C	C–A	A	A	A
Intraclasts	C	R	R	–	–	–	–	–	C
Pellets	C	–	–	–	–	–	–	R	C
Terrigenous Clay/Silt	C	–	–	–	R	C	A	C	A
Algae									
Stromatolites	C	R–C	–	–	–	–	–	–	–
Oncolites	–	A	–	–	–	–	–	C–A	–
Solenoporaceans	–	A	–	–	–	–	–	R	–
Moniliporellaceans	–	–	C	–	–	–	–	R	–
Codiaceans	R	R	–	–	–	R	–	R	R
Dasycladaceans	–	–	–	–	C	C	–	C–A	–
Sponges	–	–	R	–	C	C	–	–	–
Bryozoans	–	A	A	A	C	C	–	R–A	R–C
Pelmatozoans	–	A	A	C–A	C	C	–	C	R
Brachiopods									
Strophomenids	–	–	–	–	C–A	C	–	R–A	R
Others	–	R	R	–	C	C	–	R	R
Trilobites	–	R	R	–	C–A	C–R	–	C–R	R
Ostracodes	R–C	C	R–C	C	C	C	–	C	R
Gastropods	R	C	R	–	R	–	–	–	R
Cephalopods	–	R	–	R–A	R	–	–	–	–

FIGURE 15 Generalized distribution of principal constituents of Chickamauga Group formations at Cedar Springs (from Ruppel, 1979, p. 60). A = abundant; C = common; R = rare; – = absent.

See figure 9 for details of trilobite distribution here.

hibits a diverse biota that includes abundant brachiopods (Strophomena medialis), ectoproct bryozoans, Tetradium, trilobites, and the edrioasteroid Cyathocystis. This unit, however, tends to be poorly exposed and many exceptionally fossiliferous zones may be storm deposits.

A relatively thin (2 meters) calcarenite (unit 61) containing ostracods, bryozoans, trilobites, and questionable algae, separates the preceding zone from another fossiliferous zone. This latter unit (unit 62) is marked at its base by a characteristic thin (0.3 meter) bed of Girvanella oncolites. The rocks are poorly exposed above this bed, but apparently contain an abundant fauna consisting of brachiopods, bryozoans, pelmatozoans, and trilobites. This zone grades upward into another poorly exposed interval of silty thin bedded biomicrite containing occasional discrete layers of Strophomena medialis in life position. The alternation of these otherwise unfossiliferous silty biomicrites with thin layers of strophomenids is similar to that seen in the early stages of ecologic succession due to pulse stability recognized by Walker and Alberstadt (1975) and Walker and Parker (1976) in Middle Ordovician sediments southwest of here. The pulsating nature of the terrigenous influx from the southeast apparently only occasionally provided an environment suitable for colonization by these brachiopods. With the rapid return of siltier conditions, these organisms were castastrophically buried in life position.

The top of the Witten (unit 64) contains an irregularly bedded body of biomicrite and biosparite. This unit includes abundant ramose and encrusting ectoprocts that may have produced a topographic high "mound".

The extremely varied lithologic and paleontologic nature of the sediments of the post-Benbolt interval at Cedar Springs (units 54-64) may be explained as a result of the fluctuating conditions brought about by the irregular influx of terrigenous material from the southeast. Based on the fauna and lithology, much of this interval represents deposition in a restricted, quite, muddy water subtidal environment. The brief return of algae in the upper part (field units 58-62) suggest brief periods of clearer water, perhaps shallower, deposition. The continually increasing, although periodic influx of terrigenous material is culminated in the Moccasin silts and clays at the top of the Cedar Springs section.

STRATIGRAPHIC SECTION AT CEDAR SPRINGS

Measurement commences at base of section, see Fig. 15 for general characteristics of formations.

NOTE: Unit numbers used in this description are painted on the rocks in the field west of the church road for reference:

UNIT NO.	UNIT THICK.	CUM. THICK.	DESCRIPTION
			KNOX UNCONFORMITY
1-2	1.5	1.5	Five Oaks Formation - NEXT 4 UNITS: Blackford Member: Greenish gray dismicrite and dolomicrite locally containing large (up to 6cm) rounded chert and dolostone clasts from subjacent Knox Group. TOTAL BLACKFORD MEMBER 1.5 METERS.

UNIT NO.	UNIT THICK.	CUM. THICK.	DESCRIPTION
3-11	6.3	7.8	Brownish gray thin to medium bedded, internally laminated pelmicrite and pelsparite, commonly dolomitic, with ostracodes and trilobites increasing upward.
12-16	8.2	16.0	Similar to units 3-11, but more thickly bedded with common internal laminae and adundant birdseyes.
17-19	7.5	23.5	Medium gray-brownish gray stylolitic biomicrite and biosparite with birdseyes, internal laminations, thick beds, ostracodes, Solenopora. TOTAL FIVE OAKS FORMATION 23.5 METERS.
20-21	9.5	33.0	Lincolnshire Formation - NEXT 3 UNITS: Light-medium gray biomicrite with Solenopora and gastropods. Laterally interfingered with stromatolitic biolithite.
22-27	34.0	67.0	Light-medium gray-pinkish and biosparite, nodular weathering, stylolitic, with echinoderm debris, bryozoans Solenopora, Girvanella (oncolites especially at top of unit).
28-35	54.5	121.5	Light gray-brick red biosparite and biomicrite, shaly and nodular in upper 15m, containing echinoderm debris, bryozoans, brachiopods. TOTAL LINCOLNSHIRE FORMATION= 98.0 METERS.
36-37	13.8	135.3	Rockdell Formation - NEXT 4 UNITS: Brownish gray biomicrite and biosparite becoming buff micrite and dismicrite in middle third and thin, nodular, biomicrite and biosparite in upper third with bryozoans, ostracodes, echinoderm debris, gastropods.
38-39	17.1	152.4	Brownish gray stylolitic biomicrite and biosparite with patchy bryozoan biomicrite.
40-41	14.2	166.6	Interbedded thick light brown-greenish gray biodismicrite with ostracodes, bryozoans and gray-cream-brick red biomicrite and biosparite.
42-44	49.6	216.2	Like 40-41, but more thinly bedded, laterally continuous, thicker beds in upper 7m. TOTAL ROCKDELL FORMATION = 93.5 METERS. 1.2 meter covered interval at top.

UNIT NO.	UNIT THICK.	CUM. THICK.	DESCRIPTION
46-48	31.0	247.2	Benbolt Formation - NEXT 4 UNITS: Medium-brownish gray biosparite and biomicrite, commonly stylolitic, ledge forming, containing echinoderm debris, bryozoans, trilobites, brachiopods. Two thick covered intervals (3.7m, 13.1m) occur at 218.6m and 224.7m above base of section.
49-50	16.7	263.9	Like units 46-48, but cobbly weathering, more clay rich, locally silicified, additionally containing *Receptaculites*, *Illaenus*, *Sowerbyites*.
51-52	18.5	282.4	Brownish gray, thickly bedded biomicrite and biosparite with clay partings weathering to produce cobbly bedding. Less cobbly upward containing brachiopods (*Mimella*), *Receptaculites*, orthoconic cephalopods. A thick (7.2m) covered interval occurs at 280.6m above base of section. 1.2 meter covered interval at top.
53	30.9	313.3	Cream-brick red, crossbedded biosparite, commonly styloltic, thick bedded, with echinoderm and bryozoan debris. TOTAL BENBOLT FORMATION = 98.3 METERS.
54	20.1	333.4	Wardell Formation - NEXT 4 UNITS: Gradational from unit 53 to brownish gray biomicrite and biosparite with echinoderm debris, bryozoans, brachiopods, trilobites, sponges, *Receptaculites*.
55-56	23.5	356.9	Brownish gray-yellow-buff dismicrite, silty micrite, calcareous siltstone. A 4.3m covered interval occurs at 350.8 m. above base of section.
57	10.1	367.0	Brownish gray biomicrite with irregular bedding and yellow clay partings at base, less clay upward. Echinoderm debris and bryozoans abundant at base, smaller and less common upward.
58	1.5	368.5	Brownish gray sparse biomicrite and biosparite, irregularly bedded, more thickly bedded and clay rich upward. TOTAL WARDELL FORMATION = 55.2 METERS.
	5.5	374.0	Covered -?Bowen Formation

UNIT NO.	UNIT THICK.	CUM. THICK.	DESCRIPTION
59	4.9	378.9	Bowen Formation - NEXT 1 UNIT: Brownish gray silty micrite to calcareous siltstone. irregularly thinly bedded, locally mud-cracked. TOTAL OBSERVED BOWEN FORMATION = 4.9 METERS.
60	12.8	391.7	Witten Formation - NEXT 5 UNITS: Poorly exposed, alternating yellow calcareous shales and biomicrite-biosparite with locally silicified fossils including *Receptaculites*, *Strophomena*, trilobites, monticuliporid bryozoans, tabulate corals, *Cyathocystis*.
61	2.1	393.8	Brownish gray stylolitic thickly bedded biomicrite and biosparite.
62	4.9	398.7	Brownish gray, irregular thinly bedded biomicrite with brachiopods, bryozoans, trilobites, echinoderms debris. *Girvanella* oncolites abundant in lower 0.5 m.
63	21.3	420.0	Poorly exposed, alternating brown-bluish gray, internally laminated silty biomicrite with vertical burrows, *Strophomena* and yellow shale.
64	4.3	424.3	Brownish gray biomicrite and biosparite, irregularly bedded medially with brachiopods, ramose and encrusting bryozoans. Upper and lower with brachiopods bryozoans, echinoderm debris, *Foerstephyllum*. TOTAL WITTEN FORMATION = 45.4 METERS. END SECTION

ROAD LOG

Interval	Cumulative	
0.5	61.1	Reboard bus at top of Cedar Springs section (intersection of Church road and road to Thorn Hill). Retrace route to Knoxville.
2.8	63.9	Thorn Hill, Tennessee. Turn left on U.S. 25E (south).
6.6	70.5	Intersection with U.S. 11W. Turn right (south) toward Knoxville.
39.4	109.9	Junction with I-40. Take I-40 West toward Knoxville.

Interval	Cumulative	
3.5	113.4	Exit Business Loop.
1.2	114.6	Exit Cumberland Avenue.
1.0	115.6	Main entrance to University of Tennessee.
0.2	115.8	Intersection of Cumberland Avenue and 16th Street. END OF DAY ONE.

NOTES


START
STOP 3
STOP 4
STOP 5
STOP 6
STOP 7
N
KNOXVILLE
Fountain City
Maryville
Alcoa
Sevierville
Clinton
FRENCH BROAD RIVER
Fieldtrip Route for Day Two

DAY TWO - SHELF MARGIN DEPOSITS

ROAD LOG

Interval	Cumulative	
	0.0	Corner 17th Street and Cumberland Avenue START. Proceed east on Cumberland Avenue.
0.2	0.2	Main entrance, University of Tennessee, remain on Cumberland Avenue.
0.4	0.6	Intersection Cumberland Avenue (now called Main Avenue) and Henley Street, remain on Main.
0.3	0.9	Intersection Main Avenue and Gay Street, continue on Main.
0.1	1.0	Enter (go straight) Downtown Loop connecting to Interstate Route 40 East.
1.0	2.0	Enter Interstate Route 40 East toward Asheville.
1.4	3.4	Outcrops of Ottosee Formation on either side of Interstate at Cherry Street Exit.
0.5	3.9	Outcrop of Holston Formation grainstones on left (north) side of Interstate.
1.1	5.0	Outcrop of Holston Formation bryozoan boundstones and pelmatozoan grainstones on right (south) side of Interstate.
0.6	5.6	Rutledge Pike Exit (U.S. Route 11W), continue east on Interstate Route 40.
0.3	5.9	Quarry in Holston Formation to right (south) side of Interstate. The Holston here is unlike that at Stop 4 in that the unit contains stromatoporoid colonies and rather abundant red algae (<u>Solenopora</u>).
2.4	8.3	Asheville Highway Exit (U.S. Route 11E), continue east on Interstate Route 40.
0.2	8.5	Holston River.
1.2	9.7	Holston Formation outcrops near west end of road-cut on left (north) side of Interstate. The Holston is thinner here (about 20 m.) than in South Knox-ville. The Holston is overlain by a relatively thin Chapman Ridge sandstone which outcrops on

		both sides of the Interstate at overpass. Ottosee Formation shales outcrop in the extreme eastern end of the roadcut on the left (north) side of the Interstate.
3.0	12.7	Weathered outcrop of Ottosee Formation on right (south) side of Interstate.
2.8	15.5	Cherty residuum from Knox Group on both sides of Interstate.
0.3	15.8	Intersection of Interstate Route 40 East and Midway Road. Take Exit Ramp to Midway Road.
0.3	16.1	Midway Road. Turn left (north) toward Thorngrove.
0.3	16.4	Turn right to enter Entrance Ramp to Interstate Route 40 West.
0.3	16.7	End of Entrance Ramp, disembark from bus. This is Stop 3, which encompasses the road cuts along Interstate Route 40 and the Midway Road Exit and Entrance ramps.

STOP 3: LENOIR, HOLSTON, AND OTTOSEE FORMATIONS: SHALLOW SHELF LAGOON, DEEPER SHELF, AND SHELF MARGINAL ENVIRONMENTS

by

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INTRODUCTION

At this stop, a virtually complete section of Middle Ordovician strata from the upper Knox Group through the Lenoir, Holston, and basal Ottosee Formations is exposed along the sides of Interstate 40. The Lenoir Formation comprises the majority of the section, being 275 meters thick at this locality. To the east, the Lenoir thins rapidly to only 10 meters thick at Boyd's Creek (9.7 km. southeast), and approximately the same in the Wildwood area (24 km. southeast). Traditionally, the Lenoir has been described as a "cobbly weathering limestone" and this exposure illustrates that characteristic. The "cobbles" are of at least two origins: (1) carbonate-rich sedimentary "boudins" that weather free of the argillaceous parts of the unit and (2) globular sponges (e.g., Allosaccus prolixus) which weather out of the unit as "cobbles".

Figure 16 is a stratigraphic cross section showing the facies relationships along strike in the belt in which Midway Road (this Stop) and Alcoa Highway (Stop 4) occur. This diagram clearly shows the interfingering relationships of lithologies within the Lenoir and between the upper Lenoir

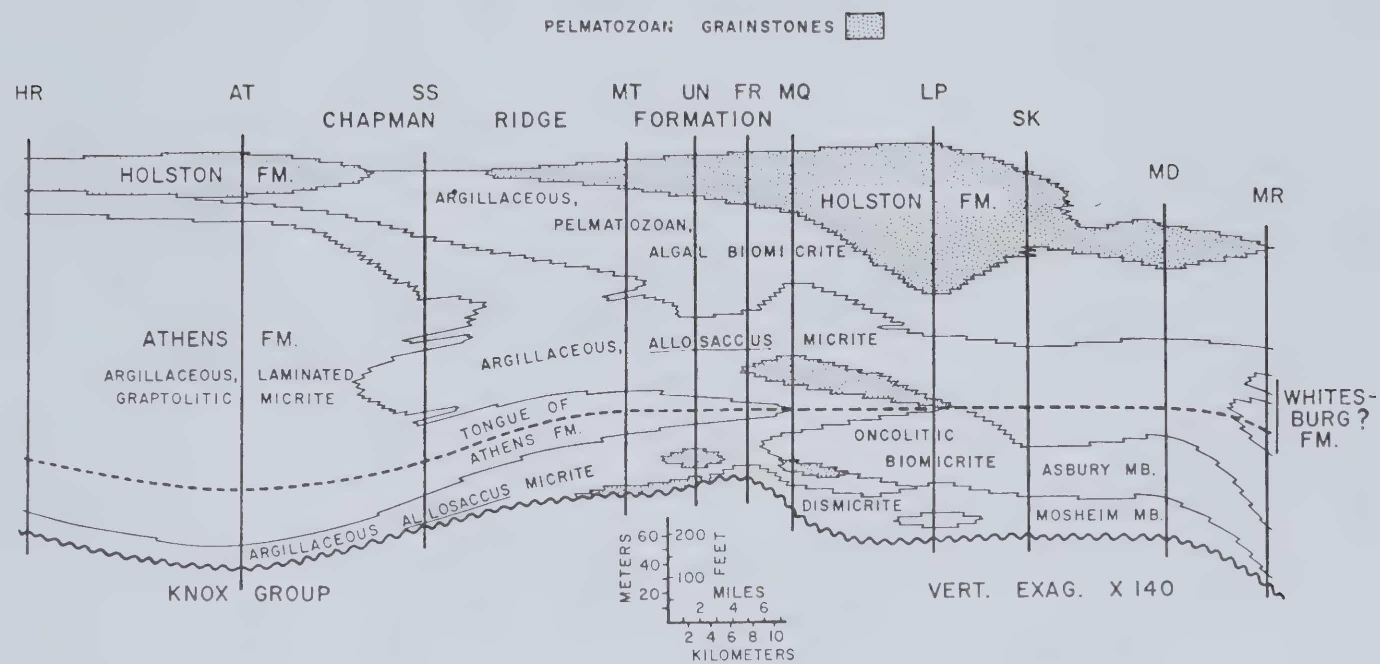

FIGURE 16: Stratigraphic cross section along strike in the South Knoxville outcrop belt showing facies changes in the lower part of the Middle Ordovician sequence displayed within one strike belt. MR = Midway Road Stop 3; SK = South Knoxville or Alcoa Highway Stop 4.

and the overlying Holston Formation. Note also the gradation southwestward (toward the left) of the Lenoir into the deeper water, dark, graptolitic micrites of the Athens Formation.

Figure 17 is a map view of the Stop 3 area showing the location of each of the rock units and other points of interest in the area. Figure 18 is a generalized stratigraphic section showing general biotic, lithologic, and geochemical data. Using these data and others, we have inferred paleobathymetric changes through time at this locality. This exposure is divided into three outcrops (fig. 17) which will be discussed in stratigraphic order from the top of the Knox Group to the Ottosee Formation. Compare the succeeding discussion of detailed depth and environmental changes through time at this section to those shown in figures 4 and 5 (in the Introduction to this guidebook) on a regional scale.

OUTCROP A

Mosheim Member

We will begin our examination of this exposure at the western end of outcrop A (north side of I-40) and proceed (up section) to the eastern end of the exposure. Exposures of the Mosheim Member of the Lenoir Formation are best seen in the cedar thicket north of the highway right-of-way fence. The Mosheim unconformably overlies dolomites of the Knox Group. The Mosheim is a dense micrite to dismicrite (fig. 19b) characterized by a sparse biota dominated by gastropods and smooth ostracods (Leperditids). Trilobite fragments are present but rare, as are algal grains (Hedstroemia). The Mosheim is also characterized by a variety of fenestral fabrics (birdseyes), algal (?) laminations, and occasional desiccation features. The Mosheim here is very similar to the basal micrite units seen at Stop 2 (Cedar Springs). We interpret the Mosheim as a restricted peritidal unit representing the shallowest water environments at this section. Parts of the Mosheim are supratidal in origin (Stephenson et al., 1973), however, no demonstrably supratidal Mosheim has been found at this locality.

Asbury Member

Overlying the Mosheim is the Asbury Member of the Lenoir. It is characterized by an abundant algal flora including Girvanella, Hedstroemia, Solenopora, some dasyclads (Vermiporella ?) and abundant fragments of the problematical alga Nuia (fig. 19C). Indigenous faunal elements include sponges (Allosaccus prolixus and others), abundant pelmatozoan fragments, corals (Billingseria parva), bryozoans (Stictoporella, Monotrypa, and others), brachiopods, and trilobites (Pliomerops). The gastropod, Maclurites magnus, is commonly found in this interval. This unit is interpreted as having been deposited in a shallow marine, nearshore environment less than 10 meters deep.

Main body of the Lenoir

Upward in the section (fig. 18), above the Asbury member, the abundance

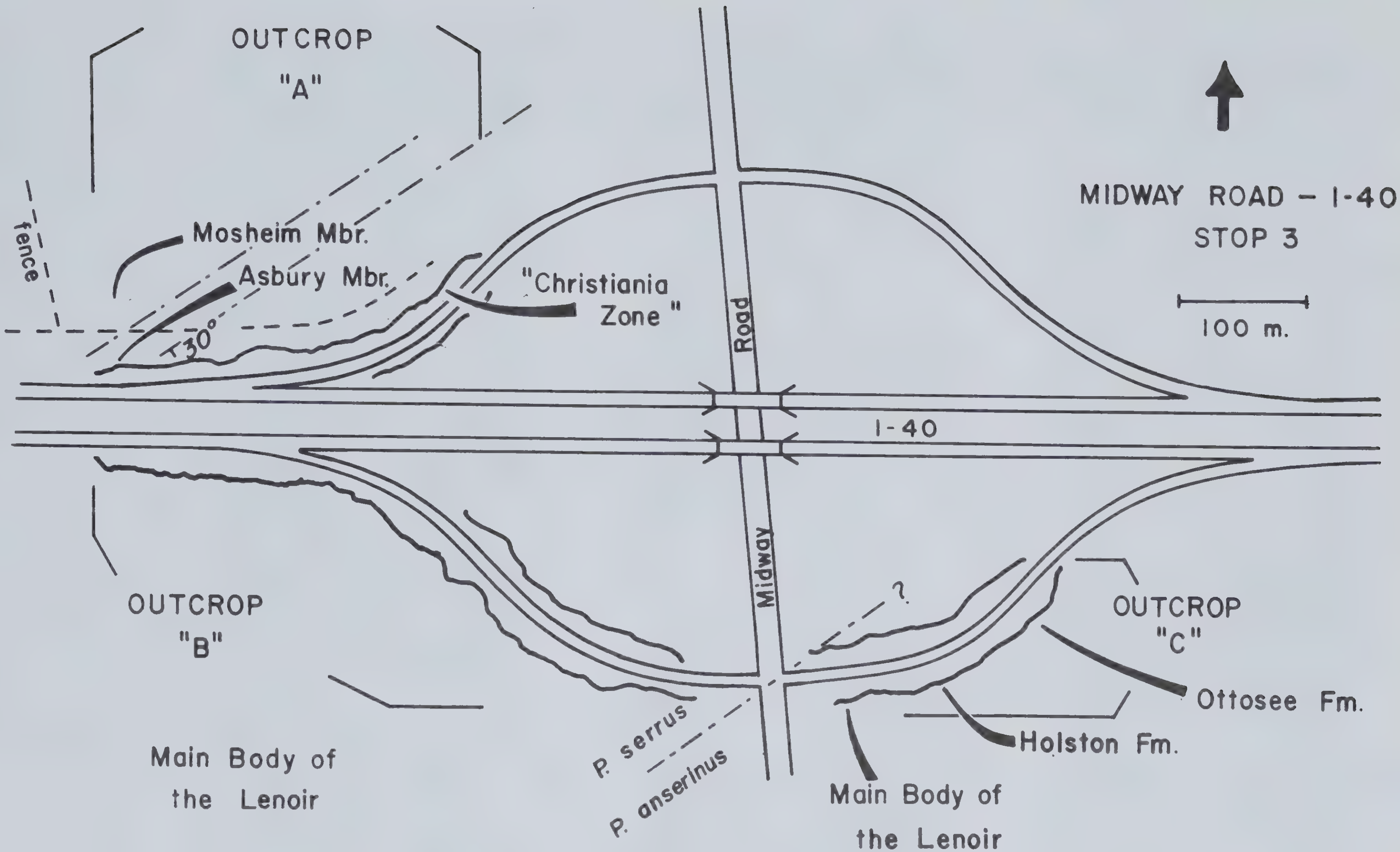

FIGURE 17: Sketch map of area around Stop 3 showing the locations of Outcrops A, B, and C, and other salient features of this locality.

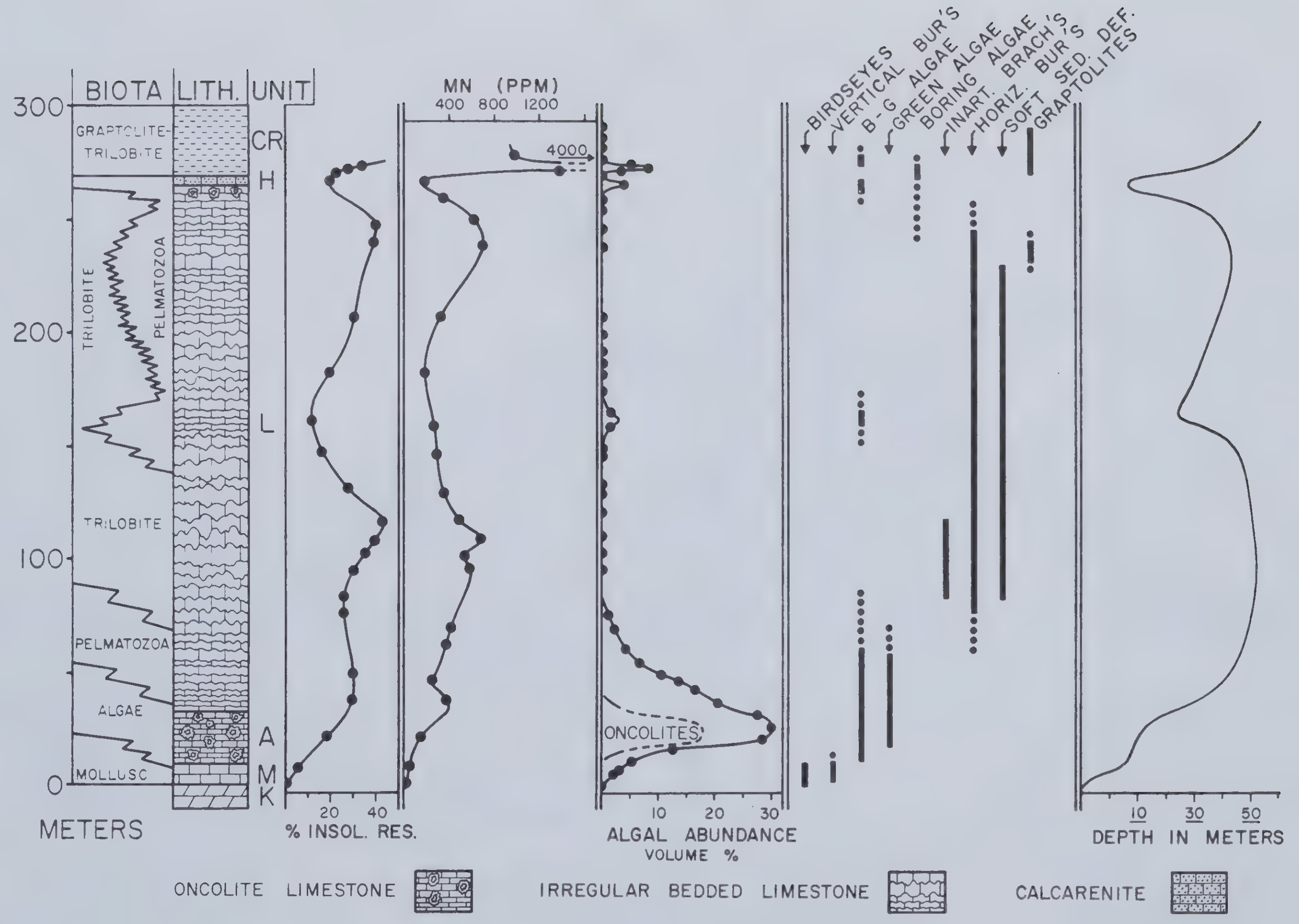

FIGURE 18: Generalized stratigraphic column of the rocks at Stop 3 (Midway Road) showing biotic, lithologic, and geochemical data. Rightmost curve shows inferred changes in paleobathemetry. From Benedict and Walker, 1978.

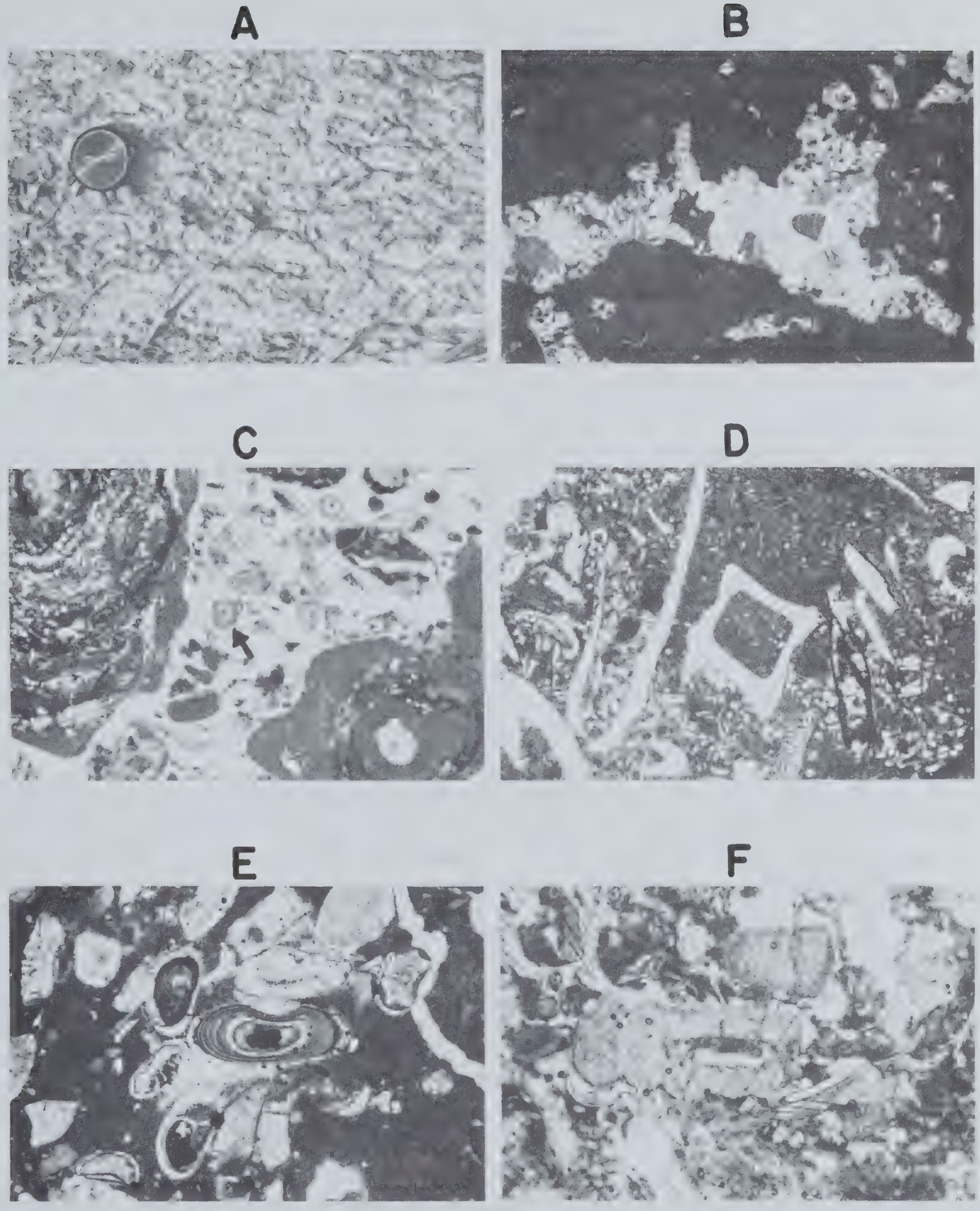

FIGURE 19: Representative Middle Ordovician lithologies at Midway Road. A. Outcrop photograph showing cobbly weathering of the Lenoir (lens cap is 6 cm. in diameter.) B. Photomicrograph of spar filled birdseye in Mosheim Member of Lenoir. C. Photomicrograph of oncolitic Asbury Member of the Lenoir (arrowed grain is the alga Nuia.) D. Photomicrograph of rectangular section of spine of the trilobite Lonchodomas which is common in parts of the Lenoir and Athens formations. E. Photomicrograph of phosphate "ooid" from the base of the Ottosee (?) Formation. F. Photomicrograph of Holston pelmatozoan grainstone. (ALL PHOTOMICROGRAPHS ARE X 15.)

of algae decreases rapidly and the biota becomes dominated by pelmatozoans (columnal debris and occasional cystoid plates), brachiopods, trilobites (Pliomerops, Isotelus, Illaenus and others mostly fragmented), and gastropods (Maclurites). This unit is the main body of the Lenoir and we interpret this zone as representing a gradually deepening subtidal environment. The eastern (upper) end of the A outcrop contains the brachiopod Christiania subquadrata and represents the "Christiania Zone" of other workers. This zone can be traced along strike to the southwest where it occurs in the western end of outcrop B south of the Interstate. After examining this zone in the A outcrop, we will proceed down the ramp to Midway Road, south beneath I40, and up the southern ramp to examine Outcrop B.

OUTCROP B

The westernmost end of Outcrop B represents the uppermost portion of the Christiania zone. The Lenoir biota is dominated by trilobites which occur as disarticulated skeletal segments (molts?) and occasionally as complete specimens. Notice in particular the common 1 to 4 cm. thick beds of varying lateral continuity at the western end of Outcrop B. A distinctive trilobite spine which is diamond shaped in transverse cross section occurs commonly in this part of the section (fig. 19D). This spine which belonged to the trilobite Lonchodomas is also common in part of the Athens Formation which is, in part, a deeper water equivalent to the Lenoir (see fig. 16). This trilobite has been found to be characteristic of deeper water facies in other Ordovician outcrops (Maitland, 1979). Lingulid brachiopods are common in the middle part of Outcrop B (several specimens can be seen in the cut near the exit sign). These brachiopods are found in life position as well as disarticulated single valves. East of the exit ramp sign, the exposure shows minor faulting and some folding especially near stations 18-24. The biota of this part of the outcrop is co-dominated by trilobites and pelmatozoans with occasional large strophominid brachiopods (Macrocoelia ?). A most important feature of nearly all of Outcrop B is the complete absence of an algal flora; this with other features indicates to us that these rocks were deposited below the local algal compensation depth (ACD) which because of turbidity (evidenced by abundant mud) may have been as shallow as 40-50 meters. These rocks are transitional toward the lithologic character of the Whitesburg Formation (Stop 7). This assignment is shown, though questioned in figure 16. Station 31 marks the eastern end of Outcrop B. Continue across Midway Road to Outcrop C (fig. 17).

OUTCROP C

Main Body of the Lenoir, Continued

The lower part of this outcrop is covered by Midway Road, however, exposures in adjacent fields indicate biotic and lithologic similarity of this interval to the upper part of Outcrop B. In the vicinity of stations 3 and 4 noticeable biotic changes occur. Thin sections and hand samples reveal an increase in abundance of bryozoans, appearance of algae (Girvanella, Vermiporella, Nuia) and corals (Billingsaria). This lithotype is similar in many respects to the Asbury Member at the western end of Outcrop A, however, well formed oncolites are not common in this unit. Although poorly exposed because of recent slumping, the Lenoir becomes increasingly pelmatozoan rich and micrite poor upward.

Holston Formation

The pelmatozoan grainstones (station 7) represent the Holston Formation. The Holston here, in contrast to exposures only 6 miles west (see mile 9.7 of road log for today) is only 2 meters thick and pinches out almost completely at the eastern end of Outcrop C. This unit represents the distal edge of the nearby Holston sand bar and reef complex which we will see at Stop 4. Although the Holston does not contain algal skeletal material, the Lenoir below it, and a thin zone immediately above contain Girvanella, Nuia, and rare Vermiporella. These algae, however, may have been transported to this locality. The uppermost portion of the Holston just below the Ottosee Formation is very high in Mn content and contains abundant dark phosphate ooids and peloids. We believe phosphate peloids and ooids are indicative of an upwelling area at an ancient shelf margin. High manganese content, in conjunction with phosphate and the superjacent faunal changes suggest a deeper water environment. The relationship of this distal edge of the Holston rock body to the main body of the Formation can be seen clearly in the cross section of figure 16.

Ottosee(?) Formation

Above the Holston is a rapid transition to terrigenous siltstones, shales and sandstones of the Ottosee(?) Formation. The biota of the unit is dominated by graptolites, tintinnids, and trilobites, with no evidence of algae or algal activity. The graptolites at this exposure are, as yet, unstudied; however, numerous diplograptids and possible monograptids have been observed. The fauna here is in general unlike that of the typical Ottosee and the lithology is also slightly different (less carbonate content and more even, thinner lamination than usual). For these reasons, we have questioned the assignment of this unit to the Ottosee; at this locality, this interval might be assignable to the Sevier Formation (compare for example the descriptions of that unit in Shanmugam and Walker, 1978).

Conodont Biostratigraphy of Midway Road

Although a detailed conodont analysis of this section has not been undertaken, spot samples collected and analyzed by Bergstrom in 1977, provide some useful biostratigraphic information. The following discussion of the conodont biostratigraphy is excerpted from personnal communication with Bergstrom.

Conodont collections in the interval between stations 26 and 30 (Outcrop B) include Pydogus serrus, Protopanderodus varicostus, Polyplacognathus rutriformis, Belodella nevadensis, "Acodus" mutatus, Belodina monitorensis, and a number of simple cone species. This assemblage represents the Pygodus serrus Zone. It also represents the Periodon-Pygodus Recurrent Species Association (RSA) of Bergstrom and Carnes (1976) that in the Southern Appalachians is especially characteristic of rocks deposited under "deeper subtidal conditions".

The uppermost Lenoir and lowermost Holston (stations C-1 through C-8) contain specimens of Polyplacognathus sweeti (typical form), Belodina monitorensis, Belodella nevadensis, Appalachignathus sp. Periodon aculeatus, Phragmodus sp., Plectodina sp., and a few simple cone species. This is the Belodella-Phragmodus-Polyplacognathus RSA and is said to be characteristic of shallower water deposits than that of the immediately older parts of the Lenoir. Biostratigraphically, this conodont assemblage is typical of the Pygodus anserinus Zone. Thus, Bergstrom's data indicate the Pygodus serrus-Pygodus anserinus Zonal boundary is between stations B-30 (Outcrop B) and C-1 (Outcrop C). This places the boundary in the covered interval under Midway Road. Additional sampling in nearby field exposures may allow refinement of this zonal boundary.

It is interesting to note that the basal Holston at this locality occupies the same stratigraphic position, in terms of conodont zonal units, as other Holston localities investigated by Bergstrom in the Knoxville area.

In summary, we believe the lithologic, biotic, and geochemical evidence here indicates a gradual transition from peritidal conditions of the Mosheim through shallow marine nearshore environments of the Asbury to gradually deepening environments of the main body of the Lenoir. A minor shallowing event or transportation of shallow water indicators into a deeper environment occurred in the middle of the main body of the Lenoir (fig. 18) and then deepening resumed. Water depth decreased again just prior to Holston deposition or again shallow water indicators were transported to this site, but soon afterwards, deepening continued. At this time, the Sevier Basin had been established approximately 20 km. palinspastically to the east. The nearby deep water environments provided a source for phosphatic sediments and increased Mn content in this area. Later (Stop 8), we will examine sediments deposited in the deep water environment of the Sevier Basin.

ROAD LOG

Interval	Cumulative	
	16.7	Reboard bus. Retrace route to Knoxville.
13.6	30.3	Business Loop Exit, continue on Interstate Route 40 West.
0.9	31.2	Interstate Route 75 North Exit, continue west on Interstate Route 40.
1.0	32.2	Alcoa Highway Exit, take this exit and continue south on US 129, Alcoa Highway.

Interval	Cumulative	
0.2	32.4	Take left fork to enter US 129, Alcoa Highway.
0.8	33.2	Overpass Kingston Pike and continue south on Alcoa Highway.
0.3	33.5	James E. Karnes Bridge, Fort Loudon Lake; outcrops on south side of river (to left of bridge) are in upper Knox Group.
0.9	34.4	Knox Group - Lenoir Formation contact is beneath the University of Tennessee Hospital interchange.
0.4	34.8	Turn right into gravel parking lot, disembark from bus. This is Stop 4, which encompasses the road cuts in the Holston and Chapman Ridge Formations which span 0.4 miles along the east side of Alcoa Highway. We will reboard the bus at Woodson Drive near the south end of the roadcuts. Some of the cuts to be viewed here are very close to the highway; participants are cautioned to move with care.

STOP 4: HOLSTON AND CHAPMAN RIDGE FORMATIONS: SHELF EDGE SKELETAL SAND BANKS, ORGANIC BUILDUPS AND QUARTZOSE-SAND-WAVE ENVIRONMENTS

by

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The rocks at this stop represent the carbonate-shelf edge environments which restricted circulation and in part created the lagoonal environment of the Lenoir Formation (e.g., Midway Road locality, Stop 3). Also demonstrated at this Stop are the down slope, deeper water carbonate buildups of the upper Holston Formation. The organic buildups of the upper Holston are not as well demonstrated here as at some localities, but the other shelf-edge facies are better shown here. The Holston thickens and thins markedly along strike in this outcrop belt, but is near its thickest development at this locality (figure 16).

One of the common characteristics of all parts of the Holston at every locality is the great abundance of pseudofibrous and radiaxial calcite cements. These types of cement have been interpreted by other workers as representing marine cements of very early diagenetic origin.

The Stop 4 area can be readily divided into three parts, here called, outcrops A, B, and C (figure 20). Part A, which is the northernmost outcrop, consists of rocks of the lower Holston Formation. Bryozoan/pelmatozoan organic buildups are rare in this part of the Formation, and the lithologies are mostly pelmatozoan/ramose-bryozoan skeletal sands. The most striking feature of these lithologies is the large scale, debris-

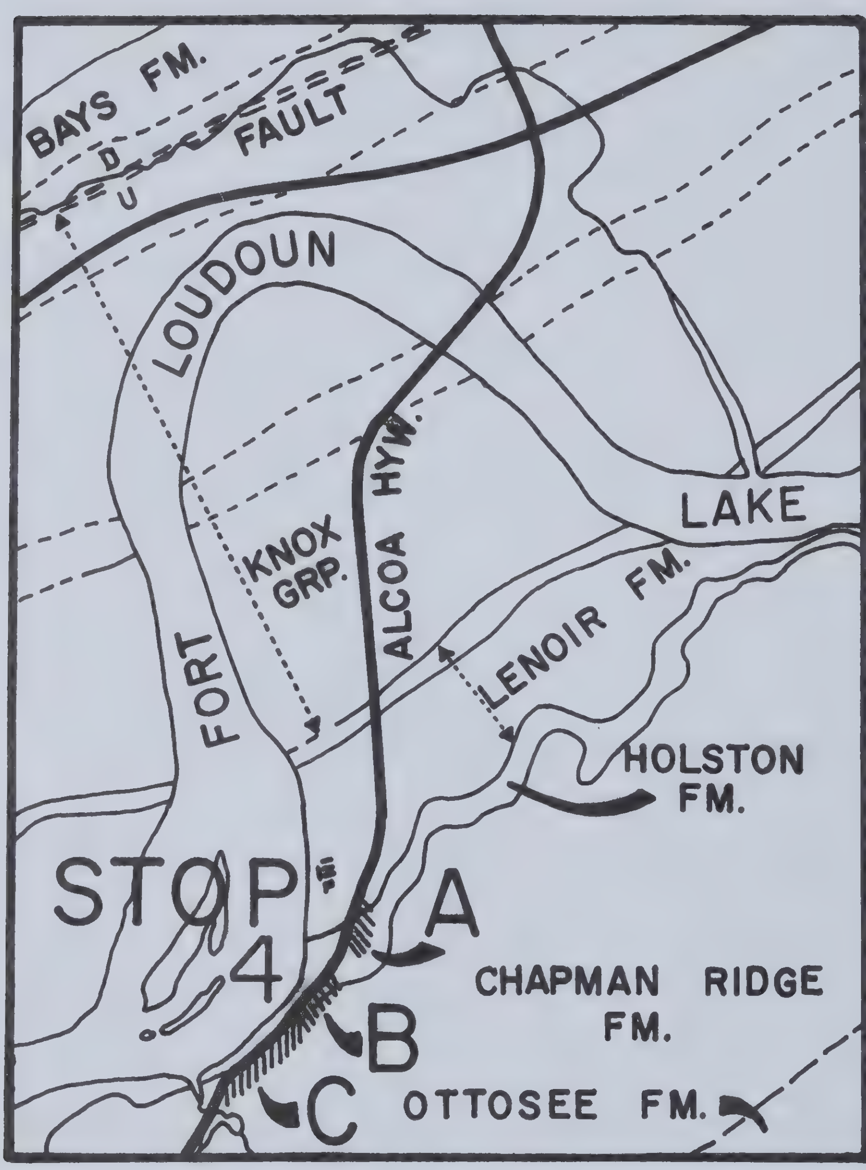

FIGURE 20: Sketch map of the area around Stop 4 , showing geology after Catermole (1958), and the location of outcrops A, B, and C discussed in the text.

slope and avalanche type cross beds (figure 21A). Note that the general dip at this outcrop is 20° to 25° to the southsoutheast, and apparent dip is less. Thus, all of the steeply dipping bed-sets here are cross-beds. Corrected dips of these sets generally exceed 30°, and the sets are roughly triangular in cross-section. Some of these sets are outlined on figure 21A. Occasional, thin sets of bidirectional cross-laminae indicate the activity of tidal, ebb and flow, currents. On the north end of the outcrop, the skeletal sands of the lower Holston are interbedded with lagoonal biomicrites of the underlying Lenoir Formation.

Because of the massive nature of Holston lithologies, the biota here is difficult to collect, and our knowledge is restricted to that derived from thin-sections and the conodont work of Bergstrom and Carnes, 1976. The megafauna consists of very abundant pelmatozoan debris, which is the dominant component of most of the sands, and less abundant ramose bryozoans. The latter group is dominated by species of Batostoma and Helopora. The bryozoan fauna is probably as diverse as that higher in the Holston, but is much less well studied. Algae are not abundant, but are present in this part of the Holston, although their abundance decreases upward. The groups present are those which characterize the upper Lenoir Formation: Girvanella (lumps), Solenopora, Contexta, and Vermiporella (see Moore, 1977). Most of the pelmatozoan debris exhibit algal and/or fungal borings. Bergstrom and Carnes (1976) have studied the conodonts of this section, and have concluded that the lower Holston here lies in the upper Pygodus anserinus Zone. This placement suggests that the Holston here is similar in age to the thin unit of Holston lithology at Midway Road.

Based on the abundant current and debris-slope cross beds, the presence of algae, and the intimate association of these skeletal sands with the algal rich biomicrites of the uppermost Lenoir Formation, we have interpreted the rocks of outcrop A as skeletal sandbank deposits. Depth of water during deposition was probably 10 meters or less. Toward the southeast, shales deposited in much deeper water are coeval with these skeletal sands. Thus, the sand-bank had a shelf edge position during deposition.

Outcrop B of this stop (figure 20), consists in part of skeletal sands similar to those of outcrop A; but the upper 20 m. is made up of pelmatozoan/bryozoan organic buildups described by Walker and Ferrigno (1973). These buildups consist of a series of anastomosing, bryozoan boundstone masses of dark red to maroon, fine-grained, lime-mudstone which we interpret as reef core deposits. The masses are surrounded and separated from each other by crossbeds of white to pink pelmatozoan/bryozoan calcarenite which are interpreted as reef-flank deposits. Reef-core facies becomes common only near the southern end of outcrop B near the top of the Holston. One small reef area here is particularly instructive. Figure 21B shows the location of this reef which is small enough to be completely exposed in this cut. Figure 22 shows the composition of the rocks composing this reef. The core facies is characterized by its high content of red lime mud. The most abundant core bryozoan is the bifoliate ramose Stictopora, the sub-cylindrical ramose Bythopora is second in abundance, followed by the incrusting Amplexopora (the latter is dominant in some core collections). Other incrusting genera (e.g., Mesotrypa, Constellaria, Hemiphragma) are present as well. The flanking beds consist of pelmatozoan grains and ramose bryozoa, dominated by Stictopora and Bythopora.

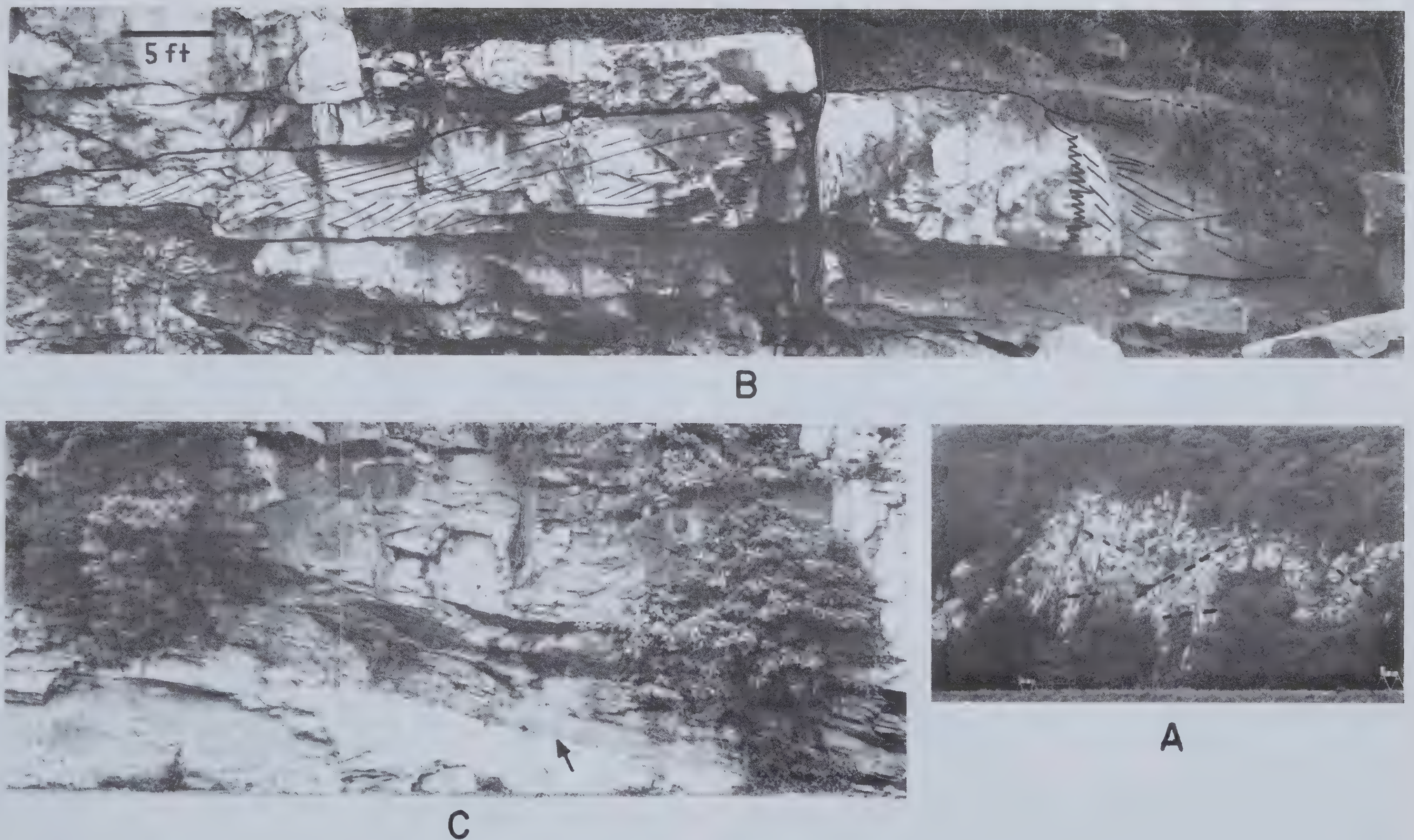

FIGURE 21: A. View of outcrop "A" along Alcoa Highway at Stop 4. Dashed lines show major cross-bed sets; outcrop is about 20 meters high. B. Small reef mass in the upper Holston (outcrop "B"); core and flank facies outlined. Scale at upper left. Details of composition shown in figure 22. C. Contact of Holston below with Chapman Ridge Fm. (darker) with shale at contact (arrow). Scale same as in B.

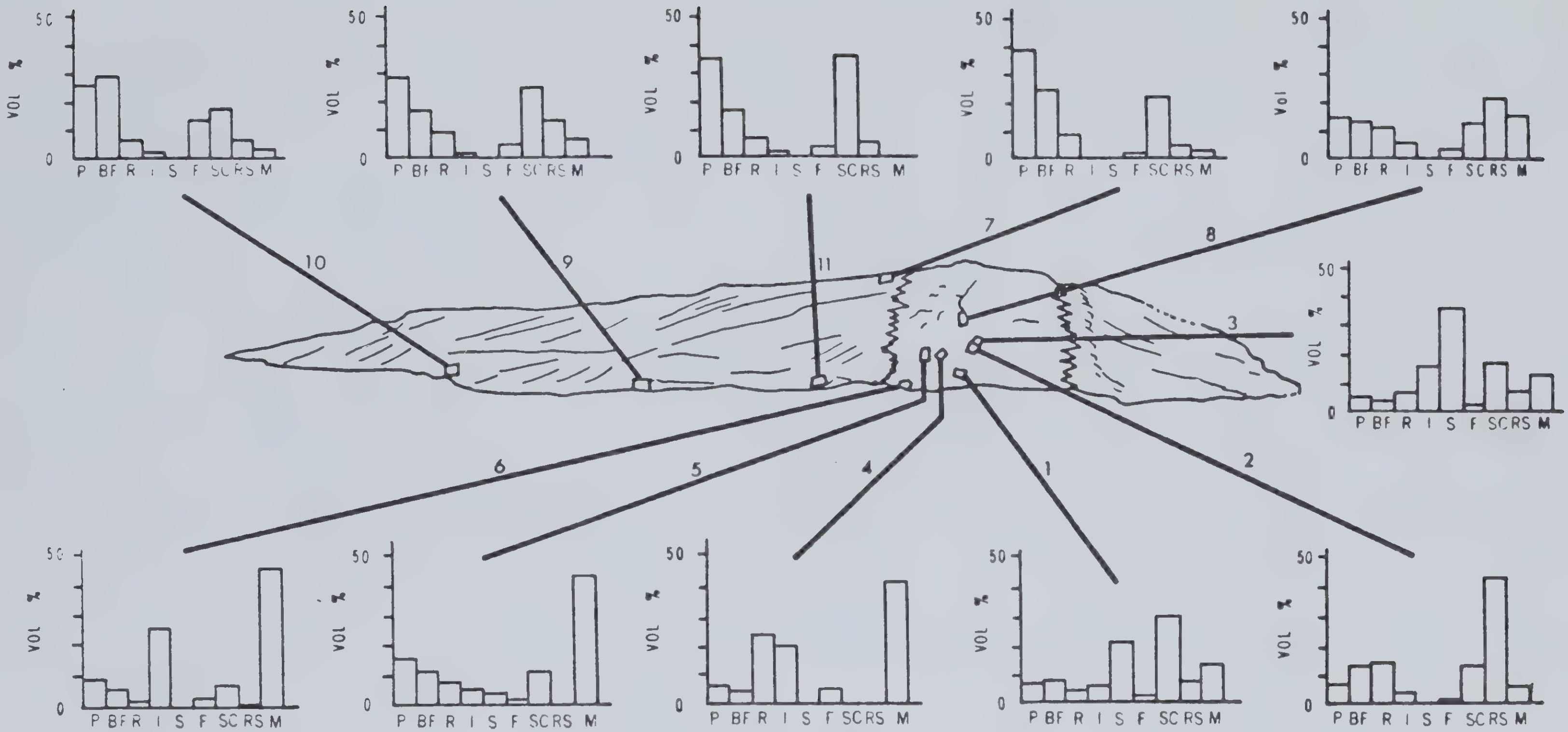

Figure 22: Alcoa Highway isolated reef core and flank sands. Sketch of the small Alcoa Highway reef showing the location and composition of samples from the two reef facies. Samples 1, 3-6, and 8 represent core; samples 2, 7, and 9-11 represent flank. Abbreviations of the components are: P = pelmatozoan debris, BF = bryozoan fragments, R = ramose ectoprocts, I = incrusting ectoprocts <u>in situ</u>, S = stromatactis structures, F = other fossils, SC = sparry calcite mosaic cement, RS = bladed replacement sparry calcite, M = fine grained matrix. Note complete absence of algae.

Incrusting byrozoa are virtually absent from the flank beds. Other core/flank complexes occur throughout the upper 20 to 30 meters of the Holston at this stop. The crossbeds in this part of the Holston are not of current origin but formed as skeletal-debris slopes.

The most significant feature of the reefy part of the Holston is the complete absence of algae. In addition, although the upper Holston was deposited along a shelf edge, current induced sedimentary structures are virtually absent. For these reasons, we believe the upper Holston was deposited below the algal compensation depth and below effective wave base at a depth of about 100 meters. An environmental model for the Holston skeletal sandbanks and reefs is shown in figure 23.

The top of the Holston is characterized in some places (as at this outcrop) by a thin, gray, nodular, shaley limestone containing phosphatic and manganiferous nodules (figure 21C). The reappearance of Girvanella oncolites indicates a slight shallowing or transportation of these normally shallow water indicators to this locality, and a corrasion surface developed on the underlying upper Holston rocks represents a period of slow deposition and submarine cementation. This unit also marks the first appearance of abundant fine grained, terrigenous clastic material in the shelf-edge sequence.

Outcrop C of this Stop begins at this nodular bed and continues southward to Woodson Drive where we will reboard the bus. This outcrop consists of variably quartzose skeletal sands of the Chapman Ridge Formation. The lower few meters of the Chapman Ridge contains little quartz silt and sand, and consists largely of pelmatozoan/ramose bryozoan skeletal sand superficially similar to the skeletal grainstones of the Holston. The Chapman Ridge lithology differs markedly from the Holston lithology, however, in its characteristic thin to medium, originally horizontal bedding and its generally darker maroon color. This lower, quartz poor lithology grades upward into rocks containing a significant percentage of quartz fine silt to fine sand and argillaceous material which are more characteristic of most of the Chapman Ridge. Current induced sedimentary structures are particularly common in all of these rocks. "Herringbone" (bidirectional) crossbedding indicates the action of tidal currents, and ripple-drift lamination the activity of wave induced currents. Gently dipping sets of low angle cross laminae become common a few tens of meters above the base of the Chapman Ridge. The current crossbedding of this formation is distinctly different in character from the debris-slope crossbeds of the underlying Holston. Tracks and trails left by invertebrates are abundant on many bedding planes; some surfaces are crowded with trilobite resting tracks. Many bed surfaces show oscillation ripple marks. Small scale festoon crossbed sets occur only rarely in the Chapman Ridge. The skeletal fauna is dominated by pelmatozoa debris, trilobite fragments, and ramose, bifoliate bryozoans (Pachydictya and Stictopora). Some of the physical and biogenic sedimentary structures of the Chapman Ridge are illustrated in figure 24. The presence of skeletonized algae and abundant wave and current induced sedimentary structures indicate deposition above algal compensation depth and effective wave-base in a few to a few tens of meters of water. The environment is interpreted as an offshore area of subtidal sand waves.

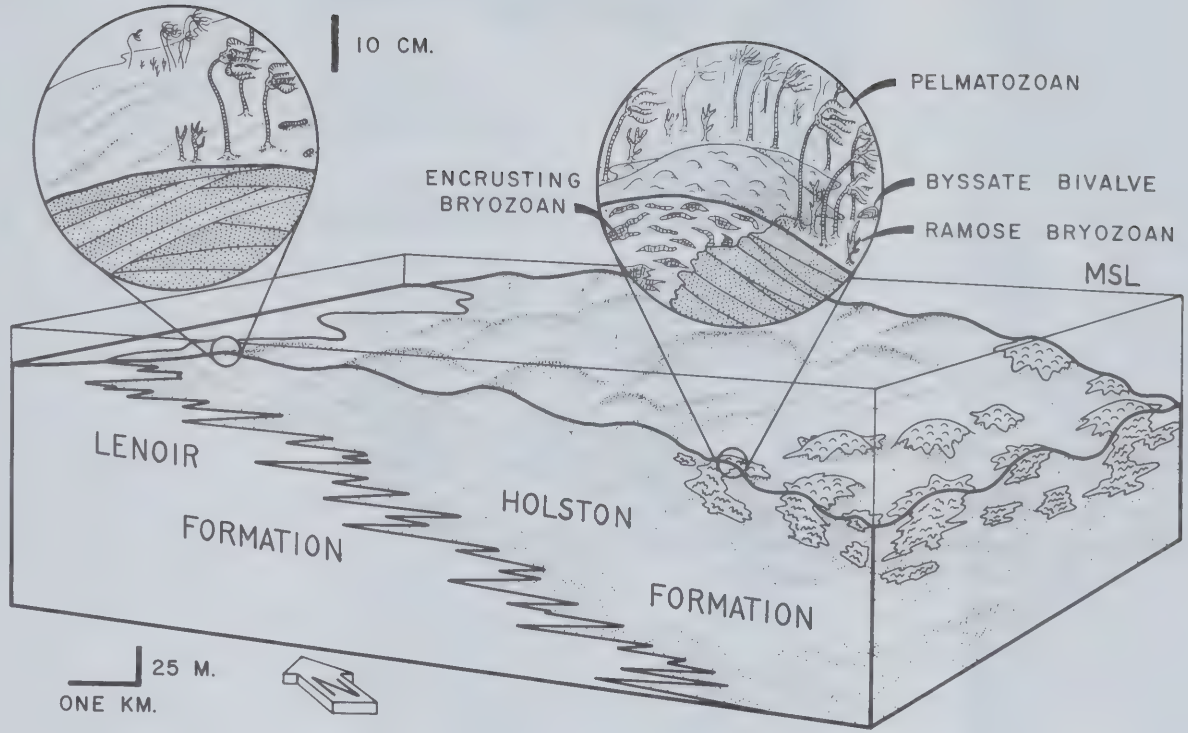

FIGURE 23: Postulated environments of deposition for the lower and upper parts of the Holston Formation. Note the intertonguing relationship with the Lenoir Formation. At many localities, the Holston has the same sort of relationship with the overlying Chapman Ridge Formation.

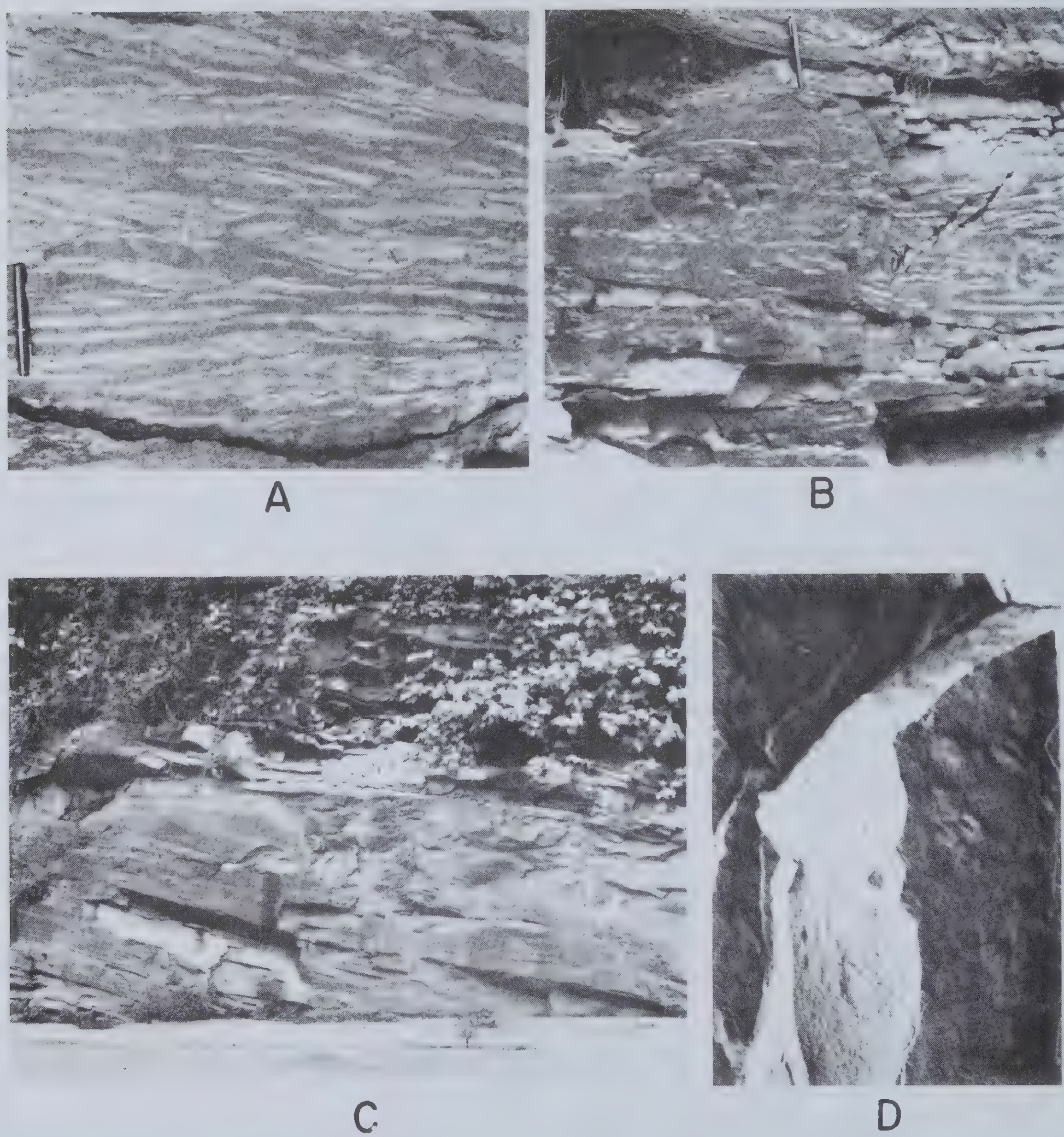

FIGURE 24: Sedimentary structures characteristic of Chapman Ridge Fm.: A. Flaser bedding, and ripple cross-lamination. Pen gives scale. B. Ripple-drift lamination. Pen at top for scale. C. Low angle, planar cross lamination. White card at right is 7½ by 13 cm. D. Under surfaces of two siltstone beds showing horizontal burrows and trilobite resting tracks. Width of field of view is about 30 cm.

The Chapman Ridge sand body grades southeastward and northeastward into deeper-water shales (e.g., Blockhouse and Sevier Formations). Toward the northwest are coeval limestones and shaley limestones. Because most earlier workers looked directly southeastward for the source region for the terrigenous silt and sand of the Chapman Ridge, they were puzzled by the absence in that direction of coeval coarse clastics in the next fault block. We believe our regional approach has cleared up that puzzle. One can see in the fence diagram of figure 2, that the terrigenous sands of the Chapman Ridge can be traced southwestward along strike from the Knoxville region to the Athens area where they can be correlated with a thick mass of very coarse, terrigenous sands to the southeast across strike in the Mount Vernon area (section MV of figure 2.)

ROAD LOG

Interval	Cumulative	
0.4	35.2	Reboard bus at Woodson Drive, re-enter Alcoa Highway (U.S. Route 129) South (toward Maryville).
0.2	35.4	Roadcut in Chapman Ridge Formation to right (west) of road.
0.3	35.7	Roadcut in intensely folded Chapman Ridge Formation to left (east) of road.
1.0	36.7	"Outcrop" of "chippy" soil typical of weathered Ottosee Formation in low roadcut to right (west) of road.
0.8	37.5	Roadcut in shales of Ottosee Formation to left (east) of road.
0.2	37.7	Roadcut in shales of Ottosee Formation to left (east) of road.
0.1	37.8	Roadcut with low outcrop of shales of Ottosee Formation to left (east) of road.
0.1	37.9	Intersection of John Sevier Highway with Alcoa Highway, turn left (east) into John Sevier Highway. Outcrops of Ottosee Formation occur in the roadcuts on the northeast corner of this intersection. These outcrops are briefly described in the description of Stop 5 below.
0.2	38.1	The roadcuts to the north and south of John Sevier Highway here are Stop 5. We will reboard the bus at the eastern end of the roadcut.

STOP 5: VARIED MIXED CARBONATE AND TERRIGENOUS CLASTIC, SHALLOW-WATER LITHOLOGIES OF THE OTTOSEE FORMATION

by

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The group of outcrops in the roadcuts at this Stop demonstrate the complex facies pattern developed during deposition of the Ottosee Formation. Figure 25 shows the distribution of outcrops around and near the intersection of John Sevier Highway and Alcoa Highway. That figure also gives some brief comments about the roadcut on the northeast corner of the intersection which we will not view directly. Figure 26 is an enlarged sketch map of the roadcut at Stop 5 which will be studied.

These outcrops are approximately 150 to 200 meters above the contact of the Ottosee with the underlying Chapman Ridge Formation; they are, thus, slightly below the middle of the Formation. The lower 150 meters of the Ottosee are characterized by limey shales, but few cleanly washed limestones. Various relatively pure carbonate lithologies become abundant only in the middle part of the Formation (as at this Stop).

At the western end of the roadcut on the north side of the road, a small patch-reef complex is exposed. This complex consists of a central maroon to dark pink fine grained boundstone with incrusting bryozoans. The bryozoans have not been studied but the core appears quite similar to core masses in the Vestal Member of the Ottosee Formation at about this same or a slightly higher stratigraphic position 2 km. northeast of Stop 5. The Vestal Member is reef-core/flanking-grainstone complex which is up to 40 meters thick and can be traced for 16 km. along strike. The reef cores of the Vestal Member are bound by incrusting bryozoans as are those in the upper Holston Formation, but also contain abundant sponges and a diverse algal flora not found in the Holston. At Stop 5, however, only a single small core-mass is exposed. It is flanked by pink to light gray, coarse pelmatozoan grainstones which at a little distance from the core are interbedded with medium gray, finer, argillaceous, pelmatozoan grainstone and medium gray, moderately fossiliferous, terrigenous mudstone. The mudstones contain subcylindrical and foliate ramose bryozoans and a few articulate brachiopods.

Upward in the section on the north side of the road the medium gray, mudstones become the dominant lithology. In some places the rocks are well bedded and fissile enough to be termed shales. Within this lithology are pods 2 to 5 cm thick and 5 to 15 cm long of medium to coarse pelmatozoan grainstone. These pods are elongate parallel to the thin bedding of the mudstone/shale lithology, and compose perhaps 10% to 20% of the outcrop. The mudstone/shale contains a largely unstudied fauna of articulate brachiopods, ramose bryozoans, trilobites, and small pelmatozoan debris. The flora here is also unstudied.

Near the center of the roadcut on the north side of the road, a zone of limey, terrigenous mudstone/shale contains abundant lace-like bryozoan colonies. The rather fragile appearing colonies are often quite large (up to 10 or 15 cm across). These colonies may, however, have been flexible in life and thus not as subject to breakage as one might conclude from

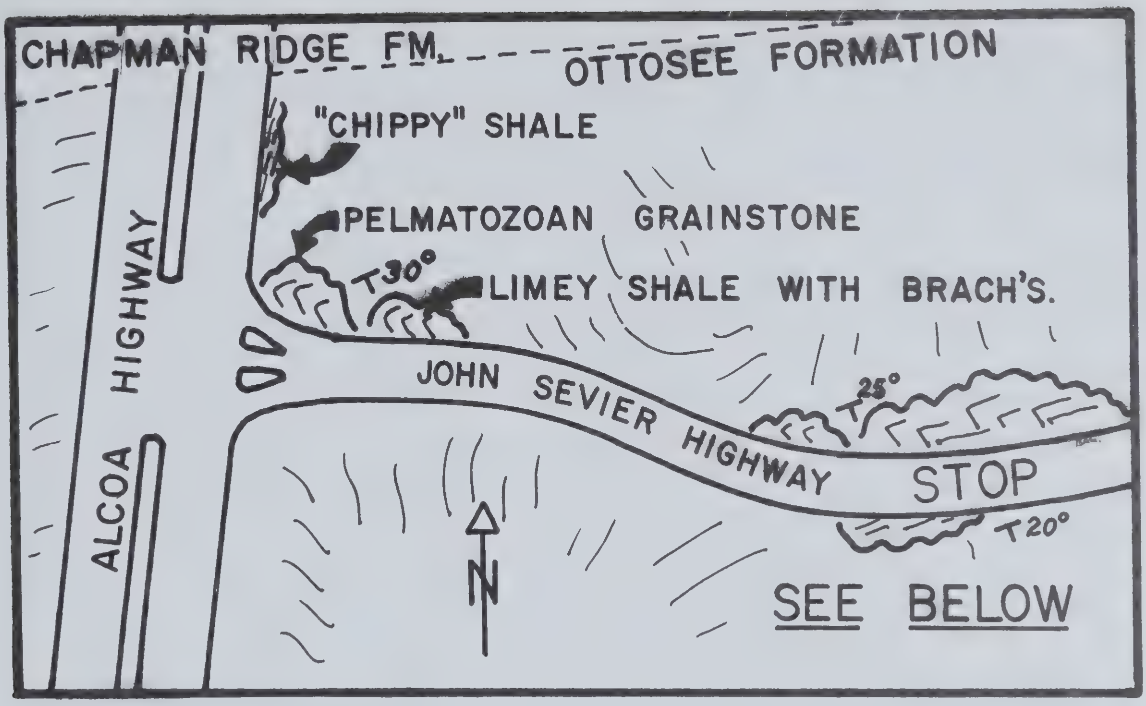

FIGURE 25: Generalized geologic sketch map of the area around Stop 5; note the lithologies in the Ottosee Forma- on the northeast corner of the intersection.

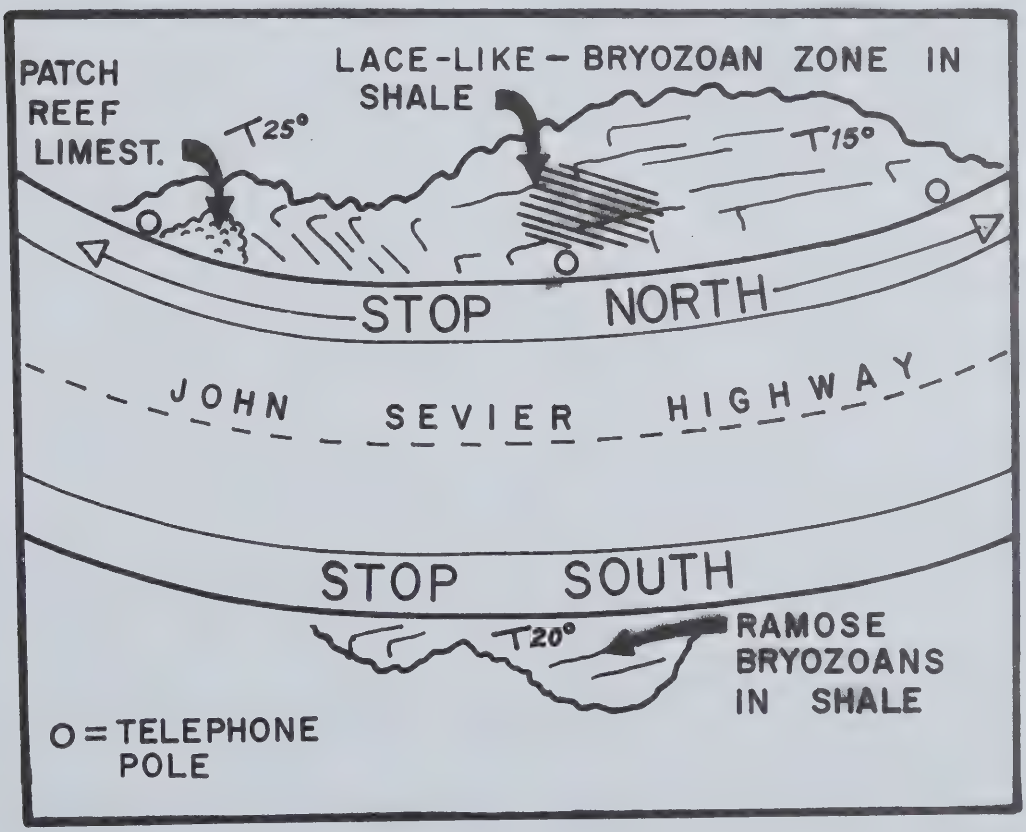

FIGURE 26: More detailed map showing the major features of the outcrops of the Ottosee Formation at Stop 5.

their delicate appearance. Their preservation here, then is not necessarily evidence of quiet-water conditions in the environment of deposition. The other faunal elements mentioned above in the stratigraphically lower mudstones may also be found with the lace-like bryozoans. Pods of pelmatozoan grainstone also occur here.

The stratigraphically highest outcrops at Stop 5 are in the smaller roadcuts south of the road. These limey mudstones are similar to those below the lace-like bryozoan zone. Discontinuous rippled laminae have lag deposits of fine grained bioclastic material concentrated in their troughs. Small diameter (2-4 mm), subcylindrical ramose and foliate, ramose bryozoans, and pelmatozoan debris are the most common faunal elements.

The Ottosee lithologies at Stop 5 were deposited in shallow water in an area subjected to irregular cyclic variation in supply of terrigenous sediment. Presence of skeletonized algae in these lithologies indicate deposition in the lighted zone; and presence of wave and current ripples suggest that deposition took place in rather shallow water. When these rocks are viewed in the context of the entire stratigraphic sequence (see figure 2), the controlling influence of cyclic subsidence of the coeval Tellico-Sevier Basin to the south becomes clear. When that Basin was undergoing renewed subsidence, terrigenous clastics were trapped there, and carbonate-rich sediments accumulated at the Stop 5 locality in the shallow-water of the shelf-edge northwest of the basin. An outcrop representing a more pronounced episode of this type will be viewed at Stop 7 at which a rather large and pure oolite body accumulated at a stratigraphic position in the Ottosee slightly higher than at Stop 5. When subsidence decreased, terrigenous clastics filled the Basin and spilled northwestward to dominate deposition along the former shelf edge (e.g., the shales of Stop 5).

ROAD LOG

Interval	Cumulative	
0.1	38.2	Reboard bus at east end of Stop 5 outcrops, and proceed eastward on John Sevier Highway.
1.5	39.7	Outcrops of Chapman Ridge Formation in roadcuts.
0.4	40.1	Outcrops of Chapman Ridge on left.
0.3	40.4	Intersection of John Sevier Highway with Martin Mill Pike. Turn right (south) onto Martin Mill Pike.
0.6	41.0	Intersection of Martin Mill Pike with Tipton Station Road, continue south on Martin Mill Pike.
0.5	41.5	Fork in road; bear right and continue south on Martin Mill Pike. Bonny Kate Elementary School on left just after fork.

Interval	Cumulative	
0.2	41.7	Poorly exposed outcrops of Ottosee Formation on right (west) of road.
0.4	42.1	Small quarry in Chapman Ridge Formation to right (west) of road.
0.1	42.2	Intersection of Martin Mill Pike with Stock Creek Road, continue south on Martin Mill Pike.
0.3	42.5	Outcrops to left (east) of road are Stop 6.
0.1	42.6	Gravel road (dump) to left, stop and disembark on Martin Mill Pike. Visibility along this road is poor, exercise caution.

STOP 6: OUTER SHELF MARGIN-UPPER SLOPE TRANSITION ZONE IN THE LENOIR AND WHITESBURG FORMATIONS

by

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Introduction

Although Middle Ordovician strata are not well exposed along Martin Mill Pike, the road cuts here will serve to illustrate the lithologies present and, more importantly, the stratigraphic relationships of the Lenoir and Whitesburg Formations in this area. The rock units here are, in some ways, similar to those we will see at Stop 8 (Whitesburg Section). The typical nodular or cobbly weathering aspect of the Main Body of the Lenoir is not well developed here, and certain typical biotic elements are rare or lacking. In some respects, parts of the Lenoir here are similar to the Athens further southwest. The Whitesburg Formation at this locality is similar to the type section of the Whitesburg (Stop 8) but, unlike the type section, it occurs here sandwiched between two tongues of the Lenoir Formation.

Our lithologic and biotic analyses of this area are still in progress, and the data presented here are preliminary. These data are based primarily on field examination and thin section petrography of samples from exposures along the hillside and valley 0.5 km. east of Martin Mill Pike, a nearly complete seasonally exposed section in the creek bed immediately west of the road, and the exposures you will see along the road. Figure 27 is a geologic map of the Stop area. The stratigraphic column (fig. 28) is a composite section derived from the three sections mentioned above. Work in progress in this area indicates that the Lenoir units thin rapidly to the east and Whitesburg-Blockhouse lithologies thicken to the south and southeast. Near Rockford, Tennessee, four kilometers south, the Blockhouse and Whitesburg lithologies are over 200 meters thick, or more than three times their cumulative thickness at Martin Mill Pike.

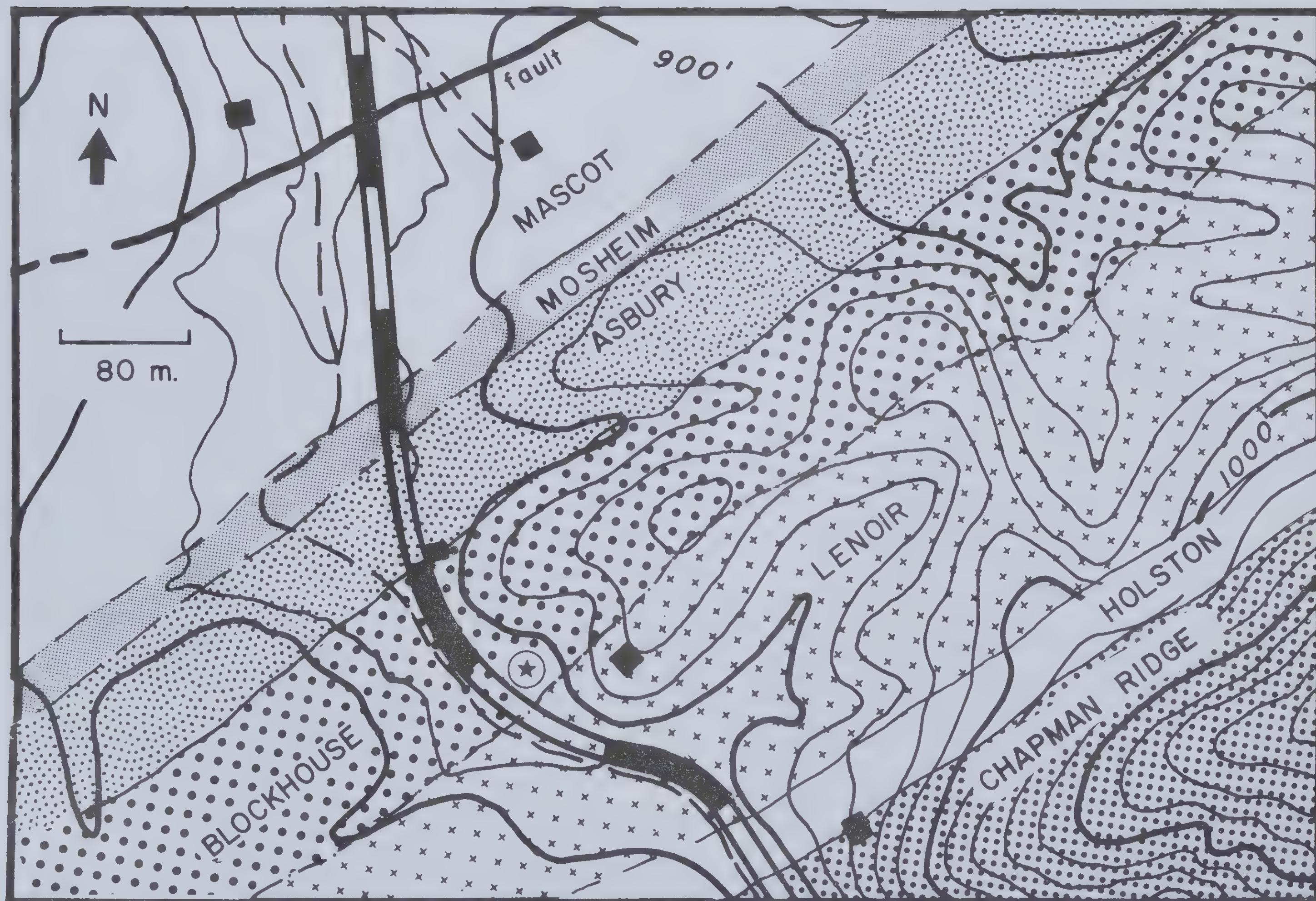

Figure 27: Geologic map of the area surrounding Stop 6 on Martin Mill Pike south of Stock Creek Church. Circled star marks the parking area for this stop. In addition to the exposures along Martin Mill Pike, good exposures of each lithology can be seen in the field and woods east of the road.

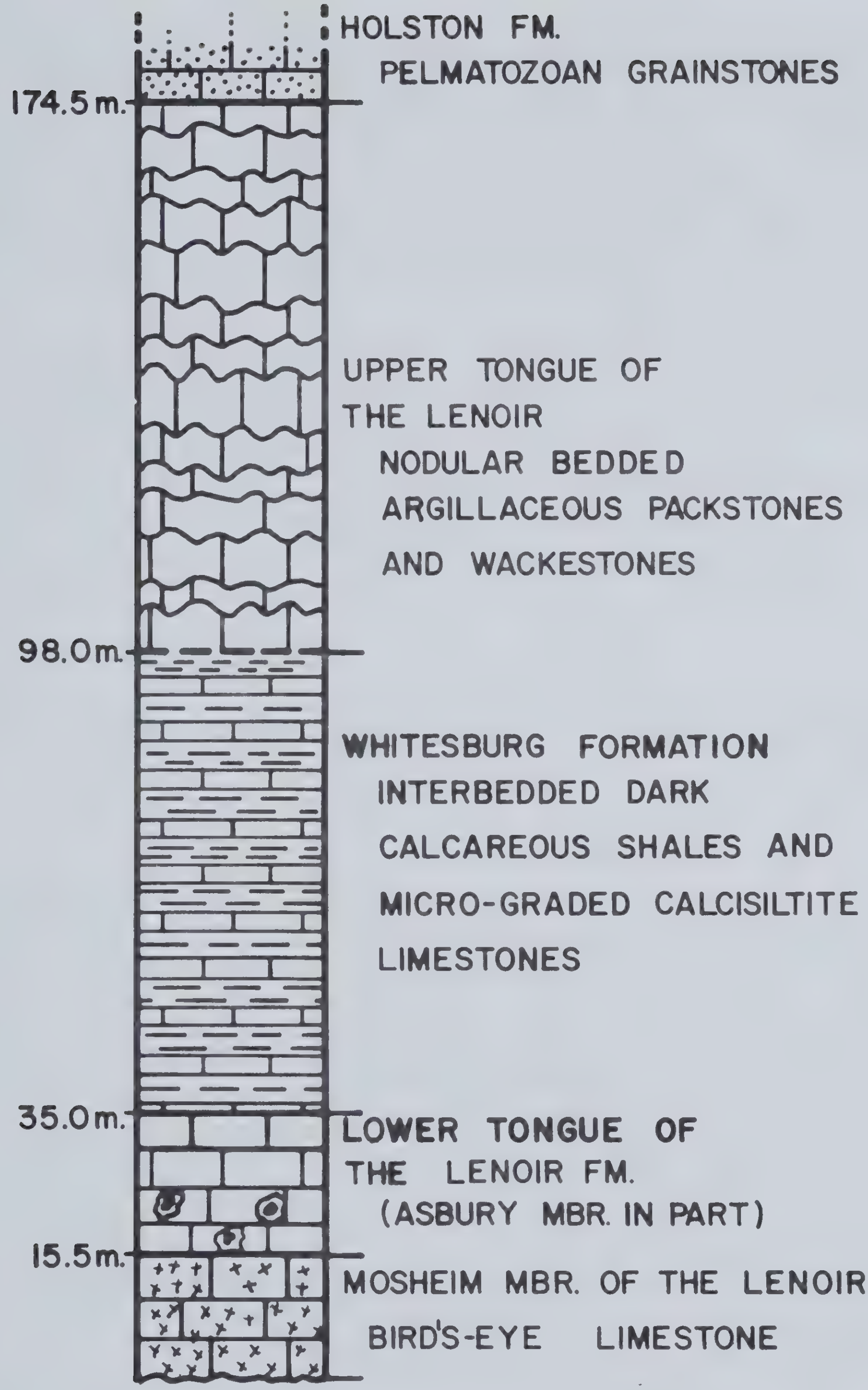

FIGURE 28: Stratigraphic column for Middle Ordovician strata exposed along Martin Mill Pike at and near Stop 6. Data presented here are derived from exposures along Martin Mill Pike , and adjacent exposures in the creek west of the road and in the fields east of the road.

Lower Tongue of the Lenoir

In the basal part of this section, a variable thickness of the Mosheim Member of the Lenoir unconformably overlies stromatolitic, dolomitic limestones of the Lower Ordovician Mascot Formation. The Mosheim averages 15 meters in thickness and can best be seen in the field east of Martin Mill Pike. Lithologically, the Mosheim comprises fenestrate (birdseye) micrites, pelmicrites, and dismicrites. It is characterized by a sparse biota of ostracods, gastropods (*Maclurites* and *Loxoplocus*), occasional trilobite fragments, and rare algal fragments (*Hedstroemia*). The Mosheim represents a protected peritidal complex of mixed supratidal, intertidal, and very shallow subtidal environments.

Immediately overlying the Mosheim Member are the oncolitic rocks of the Asbury Member of the Lenoir. This unit is poorly exposed along Martin Mill Pike, but can be traced along strike in spotty exposures for several kilometers both east and west of the road. The best exposure along the road is immediately west of the abandoned cabin near the base of the section (fig. 27). Thin section petrography reveals a rich algal flora very similar to that present at Midway Road (Stop 3) and typical of the Asbury. *Girvanella* oncolites are locally abundant as are fragments of *Hedstroemia*, and the problematical alga, *Nuia*. Unlike the Asbury at Midway Road, cephalopods, though poorly preserved, are more common here. The upper part of the Asbury at this location contains phosphatized fossil allochems and occasional phosphate ooids, features which are absent from the unit farther northwest (e.g., at Midway Road).

Whitesburg Formation

Although the contact between the Asbury and the Whitesburg is not exposed along Martin Mill Pike, it is observable 0.5 km east of the road in and around excavations for a farm pond. The contact between the Asbury and the Whitesburg is gradational over a distance of several meters. In this transition zone, the abundance of fossil allochems (especially algae) and grain size diminish up section. In contrast to the typical nodular appearance of the Asbury, the Whitesburg consists of flaggy, laterally continuous 2 to 10 cm. thick limestone beds separated by similar thicknesses of dark gray to almost black graptolitic shale resemblying the Blockhouse Formation. Thin sections reveal that the limestones are graptolitic and contain lingulid brachiopods and occasional trilobite and ostracod fragments. These limestones are graded, sand to fine silt size grainstones (calcisiltites) with approximately 20 to 35% insoluble residue. The intervening calcareous shales are composed of fine silt and clay size particles with approximately 60 to 75% insoluble residue.

The Whitesburg interval contains occasional, thin (4 to 10 cm.) but rather continuous beds of Lenoir-like lithology throughout. The thickness of the Whitesburg interval appears to be highly variable. Although our composite section shows approximately 60 meters of Whitesburg, exposures 0.5 km. to the east indicate at least 90 meters of Whitesburg at that locality. Cattermole (1962) reports over 200 meters of Whitesburg-Blockhouse 4 km. southwest of Martin Mill Pike.

Upper Tongue of the Lenoir

Although our petrologic and biotic analyses of this part of the section are incomplete at time of publication, preliminary examination indicates that the strata overlying the Whitesburg are lithologically similar to the upper part of the Main Body of the Lenoir Formation. The fauna appears to be dominated by trilobites with occasional pelmatozoan rich lenses. Thin sections from the upper part of this unit contain Girvanella and the problematical alga Nuia. The transition from Whitesburg to Lenoir is gradational and not well exposed along the road. The stratigraphically lowest exposures of the Upper Tongue of the Lenoir can be seen in the vicinity of the parking area (see fig. 27). In places, this unit resembles the Whitesburg, but is less flaggy, and more fossiliferous. Upward in the section, typical nodular bedded Lenoir lithologies can be seen along the east side of the road 30 meters south of the parking area. The Lenoir above this point is poorly exposed along the road and we will not continue up section to see the Holston pelmatozoan grainstones at the top of the section. These grainstones consist of echinoderm debris with minor ramose bryozoa; the Holston here contains none of the reefy facies such as that seen at Stop 4 , and is much thinner than at that Stop.

Summary

At this stop, we have seen evidence of the interfingering relationship of the Lenoir, Whitesburg, and Blockhouse and Holston Formations. Few localities in east Tennessee illustrate this relationship because thrust faulting has foreshortened the facies pattern, obscuring much of this transition zone. At Stop 8, we will examine coeval strata near the type section of the Whitesburg where that unit is more than 150 meters thick. Stop 9 is a basinal section in which the pelagic shales of the Blockhouse attain a thickness of many hundreds of meters and are followed by distal and proximal turbidites.

This section suggests an environmental sequence similar to that which we saw at Midway Road. An initially peritidal complex of carbonate mudstone deposits (Mosheim) and algal rich wackestones and packstones (Asbury) is succeeded by deeper water environments (Whitesburg). The deeper water environments give way to somewhat shallower water deposits of the upper Lenoir and Holston Formations. At the time of greatest bathymetry, this section seems to have occupied a position slightly deeper than the deepest deposits at Midway Road.

ROAD LOG

Interval	Cumulative	
	42.6	Reboard bus and retrace route toward U.S. Route 129.
4.7	47.3	Intersection of John Sevier Highway with Alcoa Highway, turn left (south) onto Alcoa Highway toward Maryville.

Interval	Cumulative	
0.8	48.1	Steel truss bridge over embayment of Fort Loudon Lake (Tennessee River).
0.1	48.2	At end of bridge, turn left into subdivision entrance and disembark. The outcrops 0.1 mile south on Alcoa Highway constitute Stop 7.

STOP 7: MID-OTTOSEE FORMATION OOLITE BODY REPRESENTING REJUVENATION OF THE SOUTHEASTERN BASIN

by

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In the discussion of Stop 5, I noted that a period of relatively pure carbonate deposition corresponds to the stratigraphic middle of the Ottosee Formation. This outcrop is a good example of the lithologic result of this episode which is believed to represent a period of rejuvenation of the terrigenous sediment-trapping basin toward the southeast.

The Ottosee here is near the axis of one of the minor synclines in this South Knoxville synclinorium. General bedding in this outcrop is, then, nearly horizontal and all of the non-horizontal bed surfaces seen are cross-beds. Although the top of the oolite body at Stop 7 is exposed and eroded, study of adjacent areas suggests that nearly the full, original, vertical extent of the body is exposed in the Alcoa Highway roadcut. Such lateral examination also indicates that the large lenticular shape of the body in this roadcut is probably similar to its original shape. Thus, the distal edge of the outcrop is near the original edge of the oolite shoal, and the cut is nearly transverse to the long dimension of the body. Lateral changes in lithology along the cut probably represent the facies variations across the oolite shoal.

Some of the salient features of the outcrop are shown on figure 29 and are discussed below.

The rocks of this outcrop range from oolitic pelmatozoan grainstones to nearly pure ooid grainstones and in every case carbonate muddy matrix is very minor to completely absent. Pelmatozoan rich beds tend to be most abundant near the ends of the outcrop, while purer oolite dominates the central (thickest) part of the outcrop. The oolitic rocks consist of very well sorted 1-2 mm. diameter, highly spherical ooids with many concentric laminae (up to 30-50 are petrographically resolvable in some ooids). The ooids, thus, differ from the superficial ooids with a few coatings so common in many ancient oolites. The sedimentary structures consist of small-trough, spillover-lobe, and planar cross-lamina sets quite similar to those described from modern Bahaman oolite localities by Ball (1967). Cement in the oolite consists of several generations of sparry calcite, the earliest of which consists of fine but elongate, honey colored crystals probably of very early diagenetic, submarine origin. The other generations are less well understood but probably were deposited later in the freshwater vadose and phreatic zones.

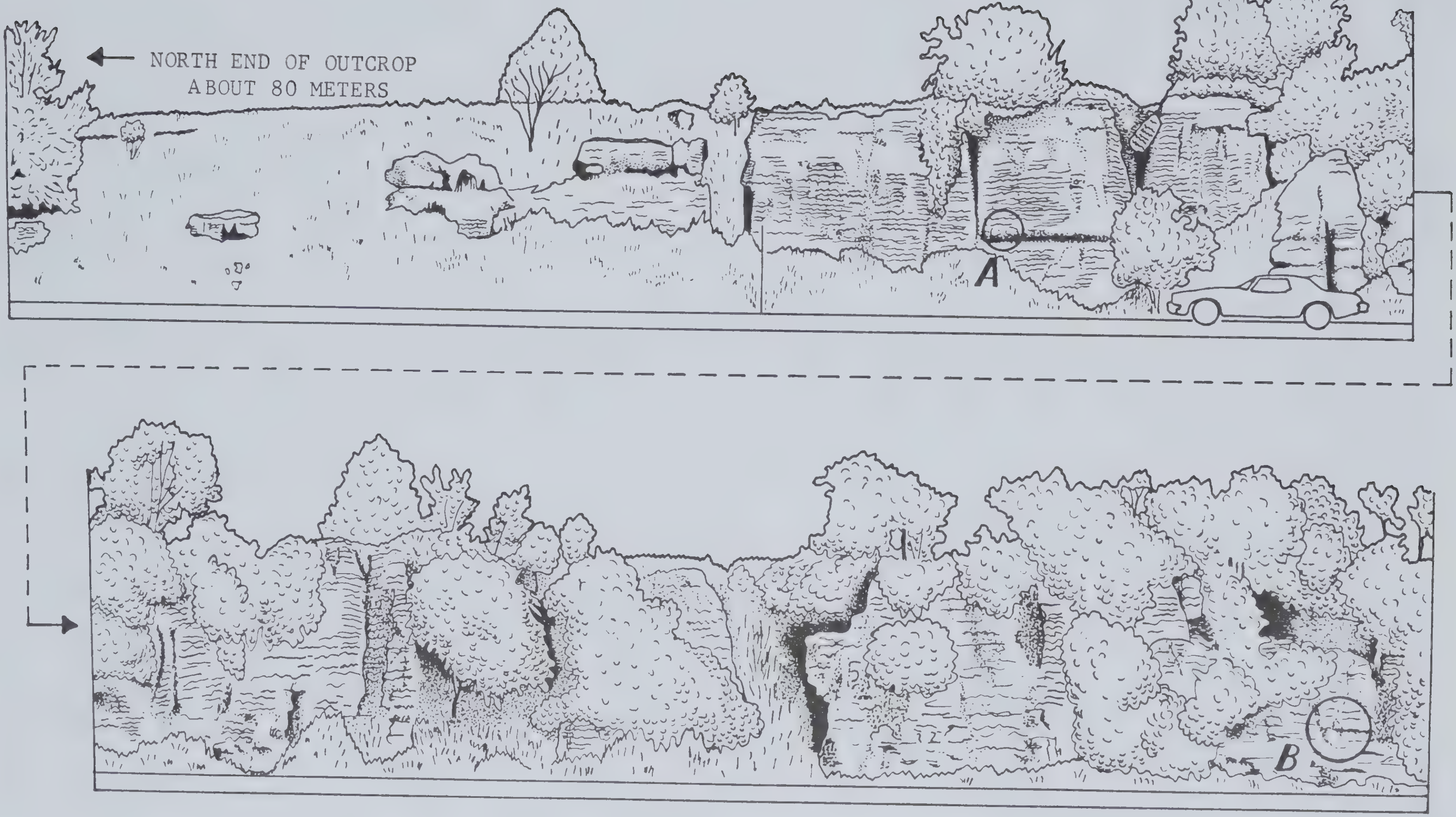


FIGURE 29: Sketch of the outcrop at Stop 7, showing the oolite/pelmatozoan sand body exposed there. Most of the outcrop consists of cross bedded oolite with abundant stylolites. Pelmatozoan grainstone is interbedded here and there especially near edges of body. Circle at "A" surrounds stylobreccia pocket; circle "B" shows area of abundant and coarse pelmatozoan debris.

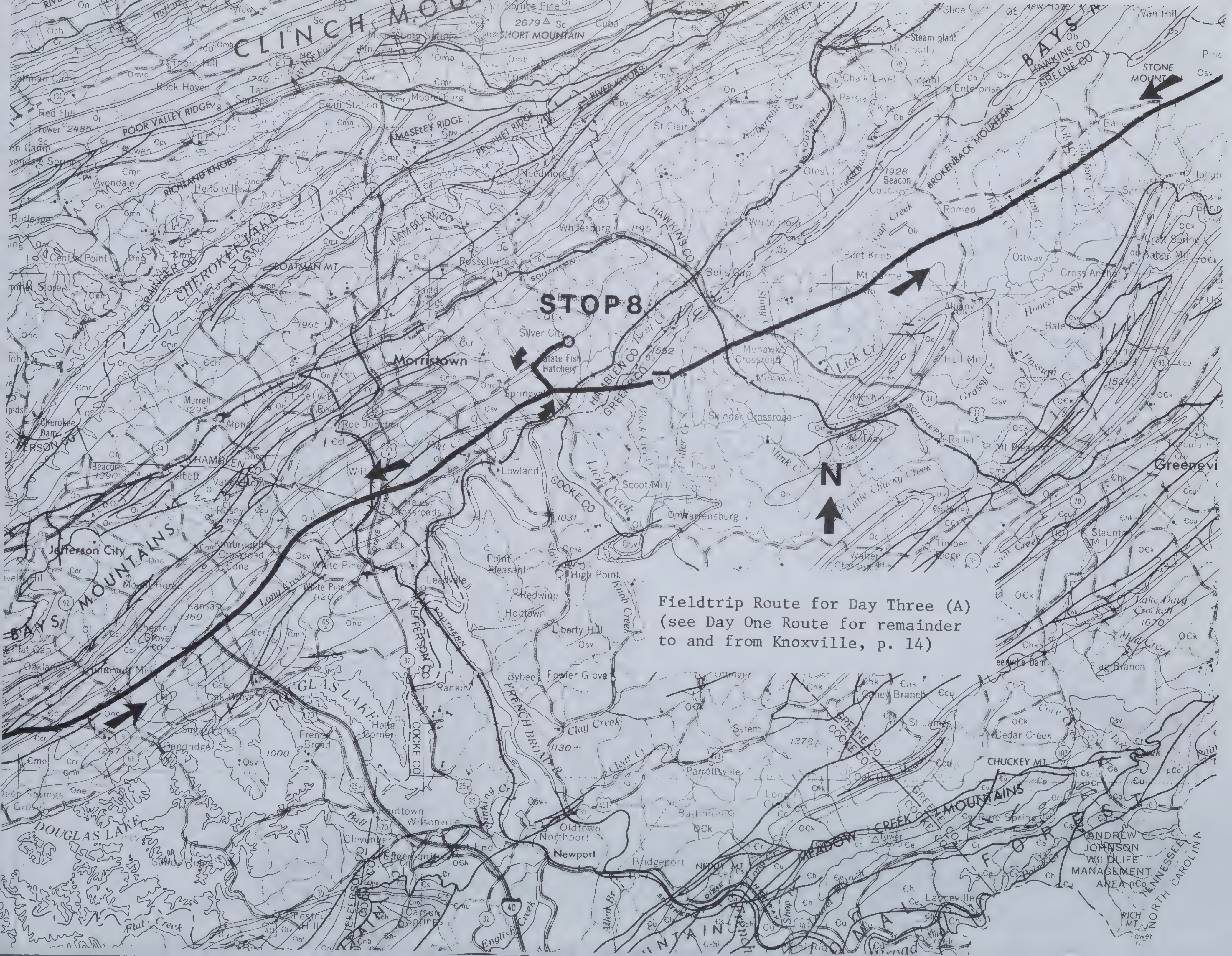
The skeletal sand lithology of this outcrop consists of medium to coarse sand to granule size pelmatozoan debris with subordinate ramose bryozoan fragments. The surfaces of the pelmatozoan ossicles usually show blue green algal or fungal borings, and often have thin micrite envelopes. These particles are cemented by syntaxial overgrowths on the single-crystal pelmatozoan ossicles followed by some blocky-mosaic sparry calcite in pore centers.

Terrigenous sediment is virtually absent from these carbonate lithologies, except that a few ooids have an angular quartz silt grain as their nucleus. Rarely, one sees isolated, rounded fine quartz sand grains, but terrigenous material in samples from this outcrop never exceeds 1 - 2 volume percent. Because the presence of appreciable terrigenous material (especially in finer grain sizes) is inimical to the deposition of skeletal carbonate material in large quantities, its absence here, coupled with the presence of physicochemically precipitated ooids and abundant fossils of suspension feeders (pelmatozoan echinoderms), indicates environmental conditions completely different from those responsible for Ottosee shale deposition. Yet this and many coeval limestone bodies in the mid-Ottosee are underlain, overlain, and laterally surrounded by terrigenous shale and siltstone. These limestone units must, then, mark some sort of temporary event; and because they are all roughly coeval, the event must have been one of regional effect. Figure 3 shows the position of this oolite in the South Knoxville (SK) section (upper cross-section) and a similar oolitic unit of even greater extent at the south Sweetwater (SS) section (lower cross section). The fence diagram of figure 2 shows a contemporaneous shallow-water reef-building event represented by the Vestal Marble Member of the Ottosee in and around the Marbledale Section (MD). Also on that diagram, another more extensive oolite body is shown near the middle of the Ottosee Formation between the Hiwasee River (HR) section and the Athens (AT) section at the southwestern edge of the study area. All of these units represent carbonate shelf margin facies such as oolite shoals or organic build-ups. Such widespread rejuvenation of a formerly terrigenous-clastic-swamped carbonate shelf edge could only occur if the delivery of terrigenous material was interrupted for a time. The presence in the regional environmental pattern of the Sevier Basin and its earlier function as a terrigenous sediment trap provides a rationale for explaining the cut-off in mid-Ottosee time of terrigenous material delivery to these localities. Apparently, renewed subsidence in that basin allowed it to regain its sediment trapping geometry for a short period, and allowed development of pure carbonate bodies such as the Stop 7 oolite at many localities on the renewed carbonate shelf edge on the northwest side of the basin.

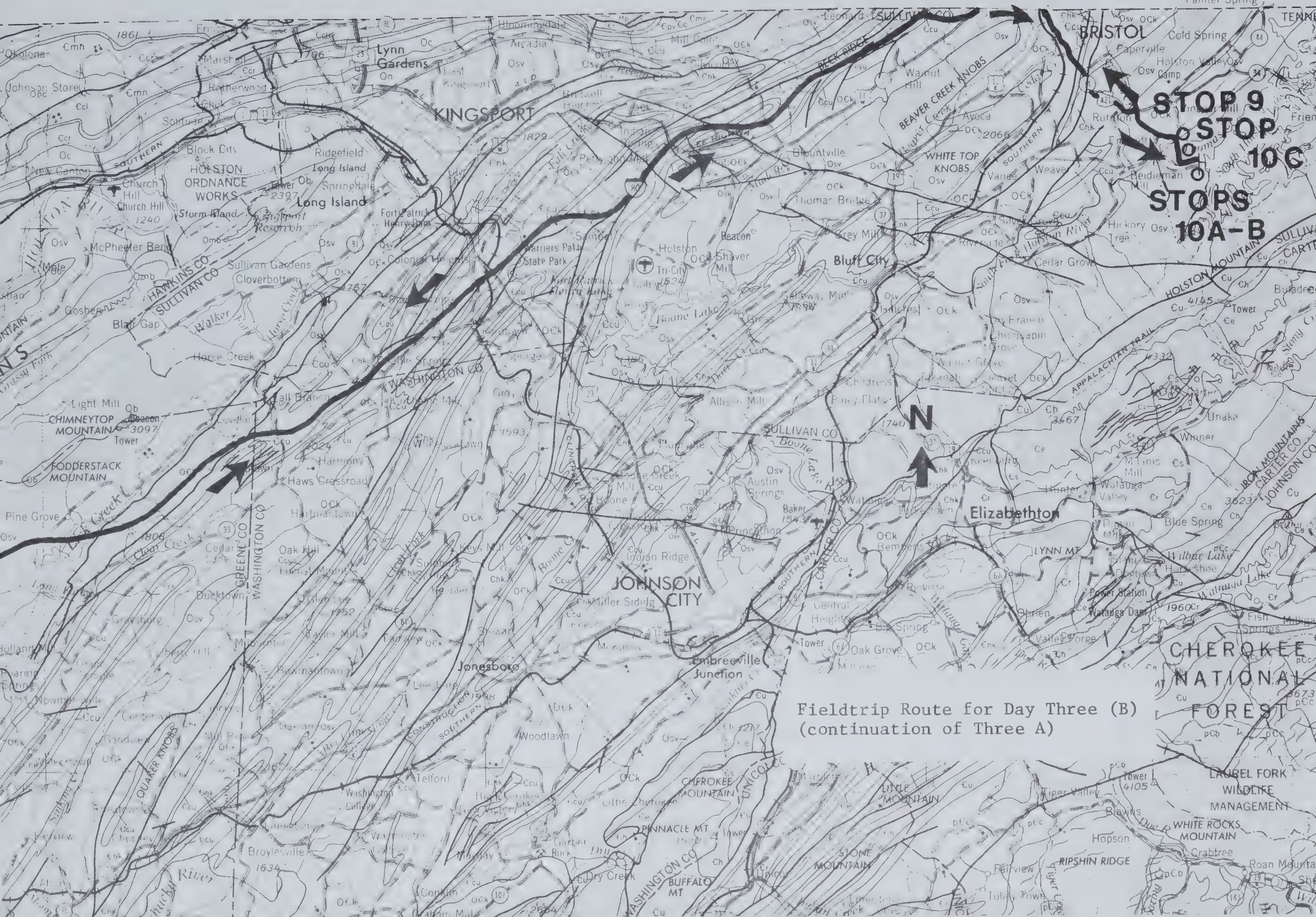
One sedimentologic feature of the rocks at Stop 7 deserves special discussion; these are the striking stylolites and associated structures of these rocks. In most places, these stylolites are of the hummocky, smooth variety as opposed to the peaked type (the latter type are more common in the pelmatozoan grainstones of the Holston Formation for example). Each stylolite is marked by a black band of stylocumulate (term after Logan and Semeniuk, 1976) from a few mm. to 1 cm. thick. Although the composition of the stylocumulate is not known in detail, it does contain high concentrations of manganese oxides and hydroxides, as well as appreciable amounts of carbonaceous material and other opaque minerals.

Hummocky stylolites are often thought to represent less solution than markedly peaked ones, but at this locality that conclusion cannot hold. If one assumes that the original surface of solution was bed-parallel and planar (admittedly a large assumption), then the relief along a segment of stylolite is a rough measure of dissolved thickness. If that is true, then as much as 1/4 to 1/3 of the original volume of this oolite body has been dissolved. In addition, at one point on the outcrop (indicated on figure 29) solution has been so severe as to produce a pocket of stylobreccia (term after Logan and Semeniuk, 1976) in which only rotated remnant blocks of an almost completely dissolved bed of oolite remain.

Interval	Cumulative	
	48.2	Reboard bus. Proceed northward on Alcoa Highway toward Knoxville. Intersection of Alcoa Highway and John Sevier Highway, continue on Alcoa Highway toward Knoxville.
4.2	52.4	South end of James E. Karnes Bridge over the Tennessee River (Fort Loudon Lake).
0.3	52.7	North end of bridge, turn right onto Neyland Drive Exit.
0.05	52.75	Bear right toward Neyland Drive.
0.05	52.8	Turn left onto Neyland Drive.
0.2	53.0	Bluff on other side (south) of lake is formed by outcrops of Lower Ordovician, upper Knox Group dolomites.
0.3	53.3	Bluff on south side of lake here is Cherokee Bluff formed by outcrops of Lenoir, Holston, and Chapman Ridge formations.
1.1	54.4	Turn left into Lake Loudon Boulevard entrance to the University of Tennessee.
0.3	54.7	Turn right onto Volunteer Boulevard.
0.35	55.05	Volunteer Boulevard becomes 16th Street and intersects Cumberland Avenue. Continue north on 16th Street.
0.1	55.15	Turn left onto Clinch Avenue.
0.1	55.25	Corner of Clinch Avenue and 17th Street.
		END OF DAY TWO.



Fieldtrip Route for Day Three (A)
(see Day One Route for remainder
to and from Knoxville, p. 14)



Fieldtrip Route for Day Three (B)
(continuation of Three A)

DAY THREE - SLOPE AND BASINAL DEPOSITS

ROAD LOG

Interval	Cumulative	
	0.0	START. Corner of 17th Street and Cumberland Avenue, proceed eastward on Cumberland through downtown Knoxville onto Downtown Loop connecting to Interstate Route 40 East. Proceed to Midway Road Exit (see Road Log for Day Two).
16.7	16.7	Midway Road Exit, continue eastward on Interstate Route 40.
9.7	26.4	Deep Springs Road Exit. Outcrops around exit are Cambrian Maynardville Limestone.
1.2	27.6	Outcrops along right (south) side of Interstate for the next 0.8 miles are Cambrian Maynardville Limestone.
7.6	35.2	Junction of Interstate Route 40 with Interstate Route 81 North. Bear left onto 81N toward Bristol, Tennessee.
7.6	42.8	Intersection of Interstate 81 North with U.S. Route 25 East (to Morristown). Continue on I-81N. Rocks exposed around interchange are Lower Ordovician Knox Group dolomites.
3.9	46.7	Lowland Exit, continue on Interstate 81 North.
1.2	47.9	Outcrops of Whitesburg Formation in roadcut on left side (north) of Interstate consist of black shales with interbedded black, slabby micrograinstones.
1.8	49.7	State Fish Hatchery Road Exit, bear right into exit ramp; at end of ramp turn left (north) onto Fish Hatchery Road.
1.5	51.2	Intersection Fish Hatchery Road with unmarked county road (T-intersection). Turn right.
1.6	52.8	The outcrops to the left (north) of the road here, and continuing for some distance away from the road (which roughly parallels strike) constitute Stop 8, Silver City. Turn left into old road at Silver City; note road cuts to right of new road 0.1 miles ahead (to east). We will begin our examination in fields to right of road just on the Silver City side of cuts and reboard near the top of the section.

STOP 8: SLOPE FACIES OF THE WHITESBURG FORMATION AND OVERLYING BASINAL PELAGIC SHALES OF THE BLOCKHOUSE FORMATION NEAR SILVER CITY, TENNESSEE

by

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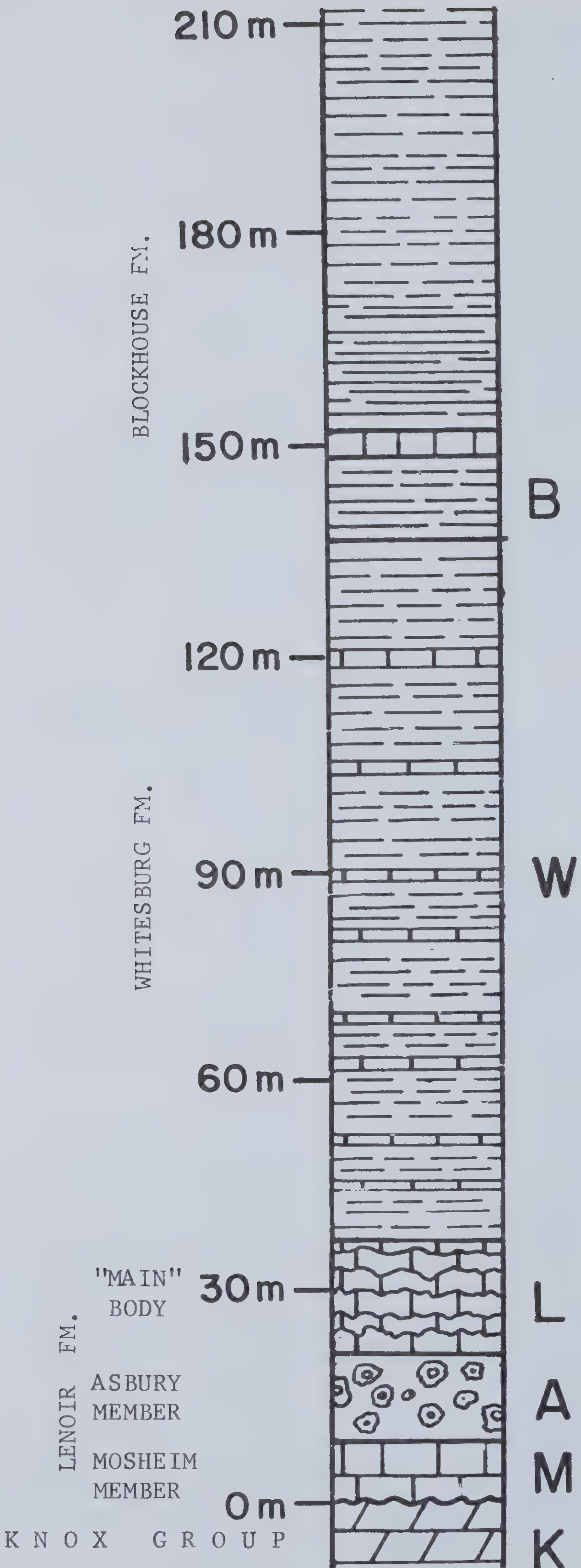
As near as we can determine, the type section of the Whitesburg Formation (Ulrich, 1930) lies about one km. to the northeast along strike from Stop 8 (the location is not clearly described by Ulrich). That section, some distance south of the village of Whitesburg, is also where B. N. Cooper (1953) made extensive collections of trilobites, and G. A. Cooper (1956) described many brachiopods. In addition, Bergstrom (1973) has carefully collected conodonts from that section and concluded that at least the lower 50 meters of the Whitesburg Formation as well as the underlying Lenoir Formation are assignable to the _Pygodus serrus_ zone. Thus, that part of the section is coeval with the lower 250 meters of the Lenoir at Midway Road (Stop 3). Bergstrom was unable to definitely assign the upper 70 meters of the Whitesburg at the type section.

In spite of this previous faunal work at the type section, we have chosen to use the section at Silver City (the present Stop) as our reference section for the Whitesburg. We do so because the Formation is much better exposed here, and the transitions from Lenoir (beneath) to Whitesburg and from Whitesburg to Blockhouse (above), which are obscured by poor exposure at the type section, can be seen clearly here.

Figure 30 is a columnar section of the Silver City locality. The sequence here rests unconformably on Knox Group dolomites and consists in ascending order of 8 meters of the Mosheim Member of the Lenoir Formation, 15 meters of the Asbury Member of the Lenoir, 17 meters of the "Main-body" of the Lenoir Formation, 106 meters of the Whitesburg Formation, followed by an undetermined thickness (but at least several tens of meters) of the Blockhouse Formation.

The lowermost part of the sequence is entirely similar in lithology to that at the Midway Road locality (Stop 3) and consists of a basal dismicrite (Mosheim Mb.) followed by the lumpy bedded, algal rich, biomicrites of the Asbury Mb. of the Lenoir Formation. But here these two basal, shallow-water facies have a combined thickness of only 22 meters, whereas at Midway Road their aggregate thickness is nearly 75 meters. The Asbury grades upward into algal-poor, nodular bedded biomicrites and sparse biomicrites of the "Main-body" of the Lenoir Formation. Again, the lithology of this unit is reminiscent of similar rocks at Midway Road, but again the interval is abbreviated (17 meters here vs. nearly 250 meters at Midway Road). Through this upper Lenoir interval there is evidence of gradually deepening water (presence of soft-sediment deformation features, absence of algae, presence of the trilobite _Lonchodomas_, etc.) and most of it is similar to the deeper-water (40-50 meters) deposits of the middle Lenoir at Midway Road.

At a point about 39 meters above the unconformity an abrupt change in



Above several hundred meters of clay shales, the Blockhouse becomes progressively more silty and grades into the silty ultradistal turbidites of the Sevier Formation (see Stop 9.)

Laminated, very dark gray to black, clay shale with graptolites. Dark grainstone bed at about 150+ meters with cephalopods, asaphid trilobites, and phosphatic ooids. Trilobites mostly Ampyx and Ampyxina with rare Robergia.

Shale similar to those of the Blockhouse but with interbedded, usually slabby very dark gray to black limestone (micrograinstone) Limestone beds 3-10 cm. thick. Lower Whitesburg limestones weather lumpy as in Lenoir. Often abundant trilobites (Lonchodomas and Isotelus in lower 81 m.; Ampyx in upper part.)

Algal poor, nodular bedded biomicrites and sparse biomicrites with Lonchodomas.

Algal rich, oncolitic, lumpy bedded biomicrites.

Massive bedded dismicrite.

Blocky weathering dolostone.

FIGURE 30: Columnar section of the Silver City stratigraphic section.

environmental conditions is marked by a 0.5 meter thick, dark gray pelmatozoan grainstone/packstone with phosphatic ooids and a high manganese content. This bed is in sharp contact above with the interbedded graptolitic shales and dark, slabby limestones of the Whitesburg Formation. As at other localities (see for example Shanmugam and Walker, 1978, 1980), this boundary marks a rather sudden deepening of water attendant on the initial pulse of subsidence which formed the Sevier Basin. From other localities we have calculated maximum water depths in that basin (Shanmugam and Walker, 1978; Benedict and Walker, 1978) to have been more than 700-800 meters shortly after basin formation. Basin floor deposition is represented at the Silver City locality by the paper-thin-laminated, graptolitic, clay shales of the Blockhouse Formation above 145 meters from the base of the section. Thus, the Whitesburg Formation (between 39 and 145 meters in the section) must represent an environment transitional between the underlying and laterally correlative shallow shelf deposits of the Lenoir and the overlying and laterally correlative basin floor deposits of the Blockhouse. In other words, the Whitesburg is the product of slope deposition.

At this Stop, the Whitesburg Formation shows its typical development. Most of the formation consists of paper-thin-laminated, fissile, graptolitic black clay-shales. Except for compressed graptolites and a small cap-shaped inarticulate brachiopod, these shales are devoid of megafossils. Tintinnines occur rarely in the thin-sections of these shales. Shanmugam and Walker (1978, 1980) have interpreted shales of this type in the Blockhouse Formation as of pelagic origin. The shales of the Whitesburg are punctuated by 3-10 cm. thick beds of very dark gray to black limestones which make-up perhaps 25 to 35% of the thickness of the Formation. In thin-section, these limestones can be classified as micrograinstones (with grains in the silt sizes). Many of them show normal grading from medium silt at the base to clay sized micrite at the top. Small scale load casts are found on the bottoms of some limestone-beds. These grainstones contain uncompressed graptolites and tintinnines, but most of the grains which are probably fossil debris are too small to identify. The limestone beds of the lower 81 meters of the Formation are characterized by the trilobites <u>Lonchodomas</u> and <u>Isotelus</u> while the limestones and shales of the upper 25 meters (as well as the overlying Blockhouse) contain the trilobite <u>Ampyx</u> (see figure 31). <u>Lonchodomas</u> (see the reconstruction on the cover of this guidebook) represents deeper subtidal shelf and upper slope environments in other Ordovician sequences (Shaw and Fortey, 1977) and <u>Isotelus</u>, though somewhat cosmopolitan in this sequence, is most characteristic of near-shelf-edge shelf environments (Maitland, 1979). Because of the graded bedding, load casts, and at least partly exotic fauna of the limestones, we believe they represent turbidites sourced on the carbonate shelf to the northwest.

The contact between the Whitesburg and overlying Blockhouse Formation is marked by a diminution of limestone beds and dominance of black shales above 145 meters in the section. These shales, as previously noted, contain compressed graptolites of mediocre preservation. They consist of biserial forms of amplexograptid and glyptograptid types lower in the Formation and a more varied <u>Nemagraptus</u> <u>gracilis</u> Zone fauna higher in the section (see Bergstrom, 1977 or Finney, 1976). One dark grainstone bed at the 156 meter level in the section (about 10 meters above the base

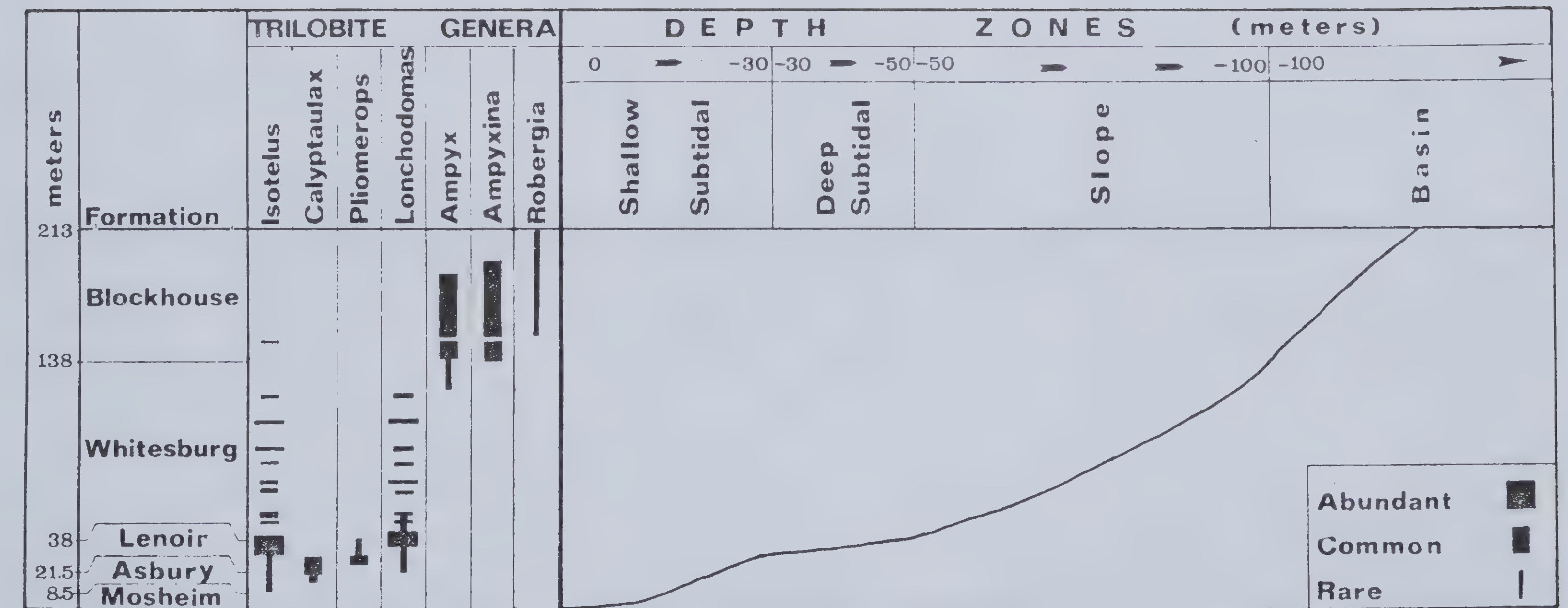


FIGURE 31: Trilobite distribution and water depth zones of the Silver City section (Stop 8). Abundant = more than 25% of the trilobite fauna in given interval; common = 5% to 25% of total trilobite fauna; rare = more than 0% but less than 5% of total trilobite fauna. A break in the bar = nonoccurrence. From Maitland (1979).

of the Blockhouse) is of particular interest. It contains abundant coiled cephalopods, asaphid trilobites, and phosphatic ooids. This lithology has at other localities been called the Fetzer Member of the Blockhouse. Because the Fetzer lithology occurs as lenses at different positions in the lower Blockhouse from locality to locality, it is probably not a useful formal lithostratigraphic unit.

The uppermost Whitesburg and the Blockhouse are characterized by a trilobite fauna dominated by the genera Ampyx, Ampyxina, and Robergia (figure 31). Some of these genera are illustrated in the reconstruction on the cover of this guidebook. This fauna consists of fragile, light, and spiny trilobites which were probably nectobenthonic or even nectonic and are representative of deeper water environments.

Thus, the Stop 8 section represents a gradual change from the shallower shelf deposits of the Lenoir to the basin floor deposits of the Blockhouse. The transitional slope interval is represented here by the 100+ meters of the Whitesburg Formation. This and similar localities are unusual because of the longer continued slope conditions which yielded an unusually thick Whitesburg interval. Further northwestward, no Whitesburg occurred and shelf deposition continued unabated. Further southeastward, the transition from shelf to basin floor occurred much more rapidly and the transitional (Whitesburg) interval is much thinner (as little as 1 meter). Because of the long but very narrow areal distribution of any slope environment, and because the Ordovician slope roughly paralleled present structural strike, much of the slope facies has been overridden by later thrust faulting. Only at a few localities (such as at Silver City) is the slope facies exposed in its full development.

The ecological changes attendant on this transition from shelf to basin conditions are well exemplified by the change in the biota. Figure 32 shows this change as expressed by the distribution of broad ecological groupings within the slope and associated facies.

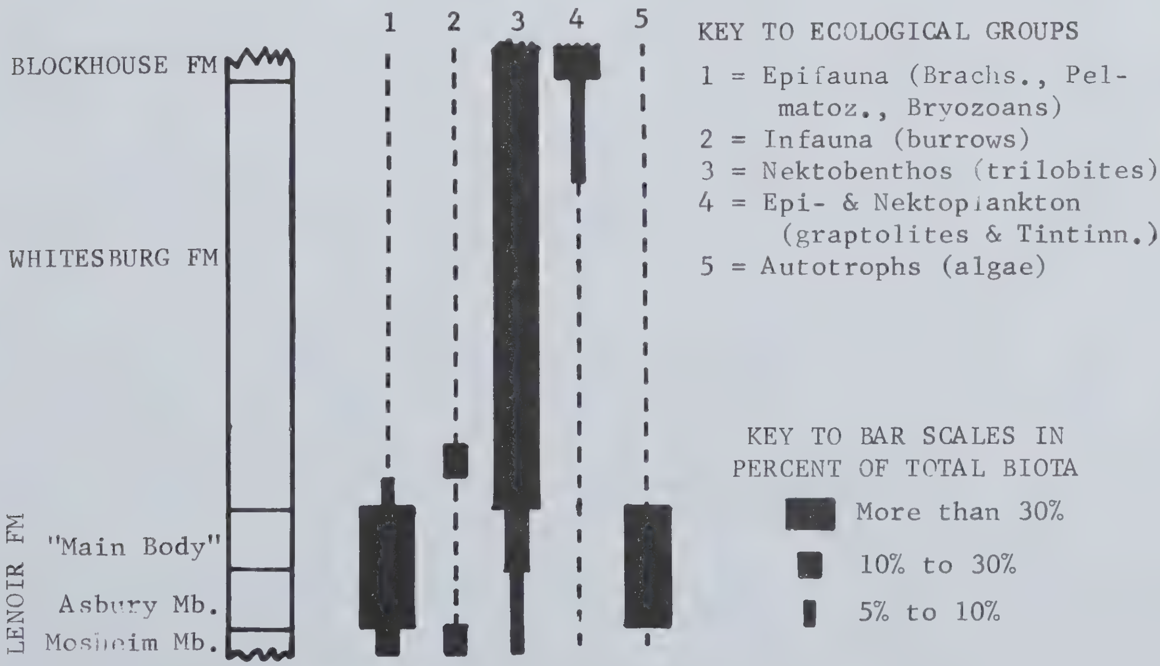


FIGURE 32: Distribution of ecological groups in Silver City section.

ROAD LOG

Interval	Cumulative	
0.2	53.0	Reboard bus near the top of Whitesburg Formation at gravel road. Retrace route to Interstate 81 North.
1.8	54.8	Turn left into Fish Hatchery Road.
1.3	56.1	Turn left into entrance ramp to I 81 N to Bristol, Tennessee.
7.5	63.6	I 81 North passes over U. S. Route 11 E at the Bulls Gap Exit. Continue northward toward Bristol.
4.3	67.9	The ridge to the north of the Interstate is Bays Mountain, type area of the Bays Formation of upper Middle Ordovician age.
15.3	83.2	Fault contact between Sevier Formation and dolostones of the Knox Group is exposed in roadcut to right (east) of Interstate.
11.0	94.2	Cambrian Honaker Dolomite overlain by Nolichucky Shale outcrops to right (south) of road.
2.7	96.9	Outcrop of Knox Group dolostones to right (south) of road.
1.8	98.7	Intersection of I 81 N with U. S. Route 23, continue on Interstate. Outcrops on north side of Interstate at intersection are Cambrian Honaker and Nolichucky formations.
0.9	99.6	Bridge over Holston River. Bluffs along river to north of bridge are composed of Knox Group dolostones.
8.8	108.4	Intersection of Interstate with Tennessee Route 37, continue on Interstate. Outcrops of Cambrian Honaker Formation on north side of the intersection.
3.7	112.1	Outcrops of Honaker on south side of Interstate.
1.3	113.4	EXIT RIGHT to U.S. Route 11 West, continue north on 11W toward Bristol, Tennessee. Outcrops around the interchange are Cambrian Honaker Formation.
1.2	114.6	Outcrops of Cambrian Nolichucky Shale on both sides of road.
0.5	115.1	Outcrops of Ordovician Knox Group dolostones on both sides of road.
0.2	115.3	Bristol, Tennessee City Limit. Continue on U.S. Route 11W.

Interval	Cumulative	
1.0	116.3	U.S. Route 11W joins U.S. Route 421S, continue on Routes 11W - 421S.
1.0	117.3	Intersection U.S. Routes 11W - 421S and Tennessee Route 381. Continue on 11W - 421S.
0.6	117.9	Turn right (south) on U.S. Route 421S (Virginia Junior Highschool on corner).
0.1	118.0	Turn left, continuing on U.S. Route 421S.
0.1	118.1	Cross Tennessee Route 113, continue on U.S. Route 421S.
0.5	118.6	Turn right, continuing on U.S. Route 421S.
0.6	119.2	Turn left, continuing on U.S. Route 421S.
0.1	119.3	Turn right, continuing on U.S. Route 421S., note sign "To South Holston Dam." After turn, view Holston Mountain on horizon.
2.1	121.4	Outcrop of lower Knox Group dolostones of Cambrian age.
1.4	122.8	Outcrop of badly cleaved Sevier Formation shales on left (north) side of road.
0.3	123.1	Turn right at sign onto North Access Road to South Holston Dam.
0.4	123.5	Outcrops of Knox Group dolostones along left (north) side of road.
0.8	124.3	Fork in road; take left fork which is North Access Road. (Right fork is South Access Road).
0.7	125.0	Outcrops of Blockhouse and Tellico formations are nearly continuous from this point to the Dam. Stop 9, basinal hemipelagites of Blockhouse Shale.

INTRODUCTION TO THE SOUTHEASTERN PHASE OF THE SEVIER FORELAND BASIN

by

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Earlier stops in this field guide have described the carbonate shelf-to-basin transition on the northwestern margin of the Sevier foreland basin. At the next 3 localities (Stops 9,10,11) we will observe slope and basinal rocks deposited along the southeastern margin of the basin, which form part of a southeasterly-derived flysch-molasse wedge eroded from tectonic highlands that developed in response to the Taconic orogeny.

The stratigraphic terminology for the southeastern phase of the Middle Ordovician of Tennessee is less complex than that of the shelf rocks to the northwest, largely because the sequence is lithologically more monotonous and because there are fewer detailed sedimentologic studies that emphasize lithologic and environmental differences in the sequence. The nomenclature applied to various parts of this interval is presented in figure 3A. The different units are preserved in two outcrop belts within the Valley and Ridge. The northwestern belt, in the lower plate of the Pulaski fault, stretches along strike the full length of the province in Tennessee and contains all the units recognized by Neuman (1955). The southeastern belt is preserved in the upper plate of the Pulaski fault and extends from southern Virginia southwestward to a point roughly 50 km south of Bristol, Tennessee. Small outliers of this belt are preserved in synclinal troughs southwestward for another 50 km. The top of the sequence in the southeastern belt is cut out by large thrust sheets of the Blue Ridge province; the Lenoir, Blockhouse, and Tellico formations are the only units present in this belt.

Four major environmental packages may be recognized in the southwestern phase of the Middle Ordovician. These packages were used by Shanmugam and Walker (1978, 1980) to define six stages in the evolution of the foredeep (fig. 33). The first package is a shallow shelf and peritidal carbonate sequence (Lenoir Limestone) that defines the first stage of basin evolution. This sequence is overlain by and is in part laterally equivalent southeastward with dark and thinly laminated "starved" basin hemipelagites (Blockhouse Shale) deposited during pronounced downwarping in the second stage of basin development. Subsidence during stage 2 is estimated to have been about 60 to 65 cm/1000 yrs. and contrasts markedly with estimated rates of 3 to 4 cm/1000 yrs. during stage 1. Stage 3 in basin evolution is represented by a flysch basin-fill of ultradistal silt and clay-rich turbidites (Sevier) that coarsen upward and southeastward into more proximal sandstone and conglomerate mass flow units (Tellico). Late in Tellico history thermohaline currents initiated contour currents that flowed parallel to the basin margin and reworked the sediments, while turbidites continued to supply clastic material to the basin (stage 4). Estimated subsidence rates for stages 3 and 4 range from 4 to 15 cm/1000 yrs. and were mainly caused by turbidite sediment loading of the crust. Stages 5 and 6 in the basin model are represented by the fourth environmental package, shelf molasse composed of shelf-edge oolite shoals (Chota Formation) and gray and red shelf mudstones, sandstone, and local patch reefs ("Restricted" Sevier of Neuman; Bays Formation) that prograded northwestward over the Tellico flysch wedge.

The pronounced and rapid downwarping during stage 2 is evidence for major tectonic activity that is generally taken to represent the Taconic orogeny in the southern Appalachians, although this orogenic pulse is probably about 10 m.y. older than the classical Taconic of the northern Appalachians. Biostratigraphic data from the Tellico and Blockhouse at Boyds Creek (Shanmugam, 1978) suggest that the major phase of subsidence occurred at roughly 465 to 470 m.y. This age is entirely consonant with radiometric dates for Taconic metamorphism and deformation in the Blue Ridge province, the earlier of which range from about 450 to 470 m.y. (Butler,1973; Kish and Harper, 1973; Dallmeyer, 1975). Most workers attribute this orogenic activity to collision of an island arc (Charlotte and Carolina slatebelts; Hatcher, 1972, 1978; Odom and Fullagar, 1973; Fullagar and Butler, 1977) and various rifted microcontinental fragments with the North American craton along an east-dipping subduction zone.

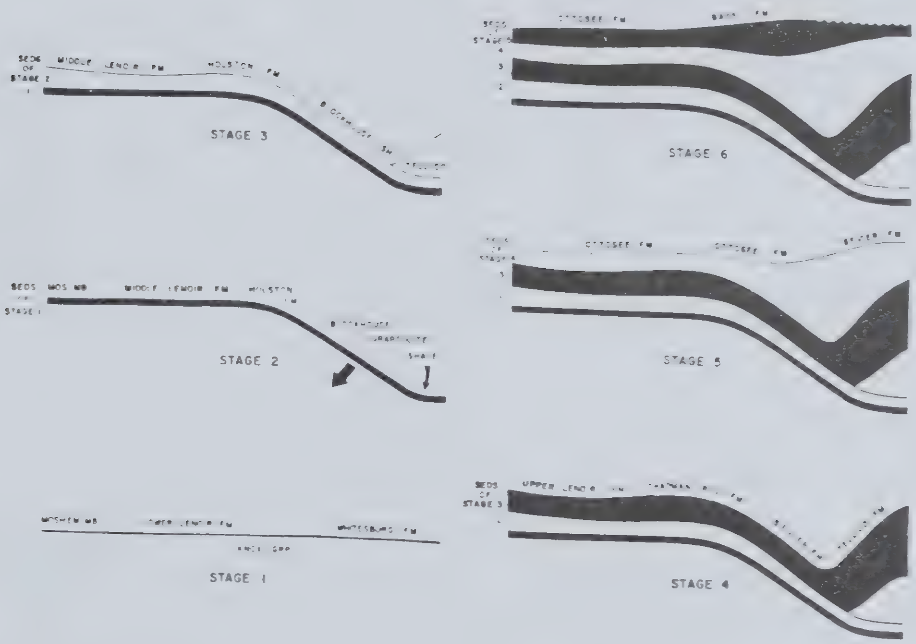

FIGURE 33. Tectonic evolutionary stages of the Blockhouse-Sevier basin (from Shanmugam and Walker, 1978), using a flexural-bending model of basin subsidence.
Stage 1, carbonate shelf stage.
Stage 2, downwarping stage.
Stage 3, turbidite-fill stage.
Stage 4, contour-current stage.
Stages 5 and 6, shelf molasse stages.

STOP 9: BASINAL HEMIPELAGITES OF THE BLOCKHOUSE SHALE

by

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This locality, which is stratigraphically near the base of the basin-fill sequence, is at least in part correlative with slope-facies limestone of the northwest margin of the basin at Silver City (Stop 8). It is the best exposure of the Blockhouse in the South Holston Dam area. The exposure consists of thinly laminated dark gray to black silty and clay shale that gives off a sulfurous odor when struck with a hammer due to abundant organic material. Graptolites may also be observed on some bedding surfaces. The shale lacks any algae or any shallow-water fauna. In other localities (e.g., at Mosheim, some 60 km. to the southwest) the Blockhouse contains small cap-shaped inarticulate brachiopods thought to be pelagic in origin.

Individual sedimentary laminae in the shale lack any internal size grading or other features such as microscopic cross-lamination or scour and contrast sharply with the thick, graded siltstone laminae in the overlying Tellico Formation (see Stop 10C). Because of its pelagic fauna, lack of traction-current features, and its fine grain size and evenly laminated nature, this shale is interpreted to be hemipelagic in origin and deposited on the basin plain. Subsequent deposition of southeasterly derived basin-fill turbidites of the Tellico built up the submarine fan complex examined in the next stop.

ROAD LOG

Interval	Cumulative	
	125.0	Reboard bus. Proceed toward base of Dam along Access Road. Outcrops of Tellico Formation are nearly continuous from roughly this point to the Dam.
0.6	125.6	Entrance gate to South Holston Reservoir.
0.8	126.4	Center of base of Dam; continue on Access Road to top of Dam.
0.2	126.6	South Access Road enters from right; continue on Access Road to top of Dam.
0.9	127.5	Center of top of South Holston Dam; continue to turn-around at Picnic Area.
0.5	128.0	Picnic Area. Turn around here and retrace route southward.
0.2	128.2	Visitor Center - Photographic Stop. View across lake to east of Holston Mountain, which is underlain by lower Cambrian clastics of the Chilhowee

Interval	Cumulative	
		Group. The Holston Mountain thrust fault is at base of the mountain. Peninsulas in lower foreground are underlain by Ordovician Tellico Formation. Reboard bus and continue southward across Dam.
0.3	128.5	Stop 10A. Disembark from bus. The following stops will be examined downward stratigraphically and show the vertical facies relationships exhibited by progradation of the submarine fan complex.

STOP 10: INCISED SUBMARINE CHANNEL-FAN DEPOSITS IN THE TELLICO FORMATION, SOUTH HOLSTON DAM, TENNESSEE

by

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Introduction

Nearly 200 m of coarse conglomerate, sandstone turbidites, and intercalated shale with the top unexposed record progradation of a major submarine fan complex in the Tellico Formation at South Holston Dam, Tennessee (fig. 34). Six major lithotypes--laminated and banded siltstone, classical turbidites, massive sandstone, pebbly sandstone, clast-supported and matrix-supported conglomerates--are systematically arranged in the section and allow recognition of sub-environments within the deposit. These rock types overlie dark, "starved" basinal shale of the Blockhouse.

Deep-water submarine fan deposits have been described from numerous modern (see reviews by Normark, 1970, 1974, 1978) and ancient (Sullwold, 1960, 1961; Walker, 1966a, b, 1978; Mutti, 1974; Nelson and Nilsen, 1974; and others) settings. According to the general model that has emerged from this work, the fan may be divided into 3 major areas, upper, middle, and lower fan, each of which is characterized by a certain morphology and suite of associated lithotypes. These features are summarized in fig. 35, which is taken from Walker (1978). The upper fan is characterized as a single leveed channel within which coarse conglomerates are deposited. The mid-fan is a complex of convex-upward depositional lobes deposited by shifting and often braided channels and is composed of massive and pebbly sandstones encased in interchannel shale and thin-bedded classical turbidites. The lower fan is an unchannelized low-gradient area that merges with the basin plain. It is composed of thin to thick-bedded classical turbidites, hemipelagites, and ultradistal silt and clay-rich turbidites. This model is a basic framework from which we may interpret deposition of the Tellico at South Holston Dam. Similar deposits in laterally equivalent parts of the Tellico Formation in the Bristol area and northward to Abingdon, Va. (Knobs Sandstone; Read and Tillman, 1977; Raymond, Webb, and Moore, 1979) document an areal extent of at least 600 sq. km. for this fan complex.

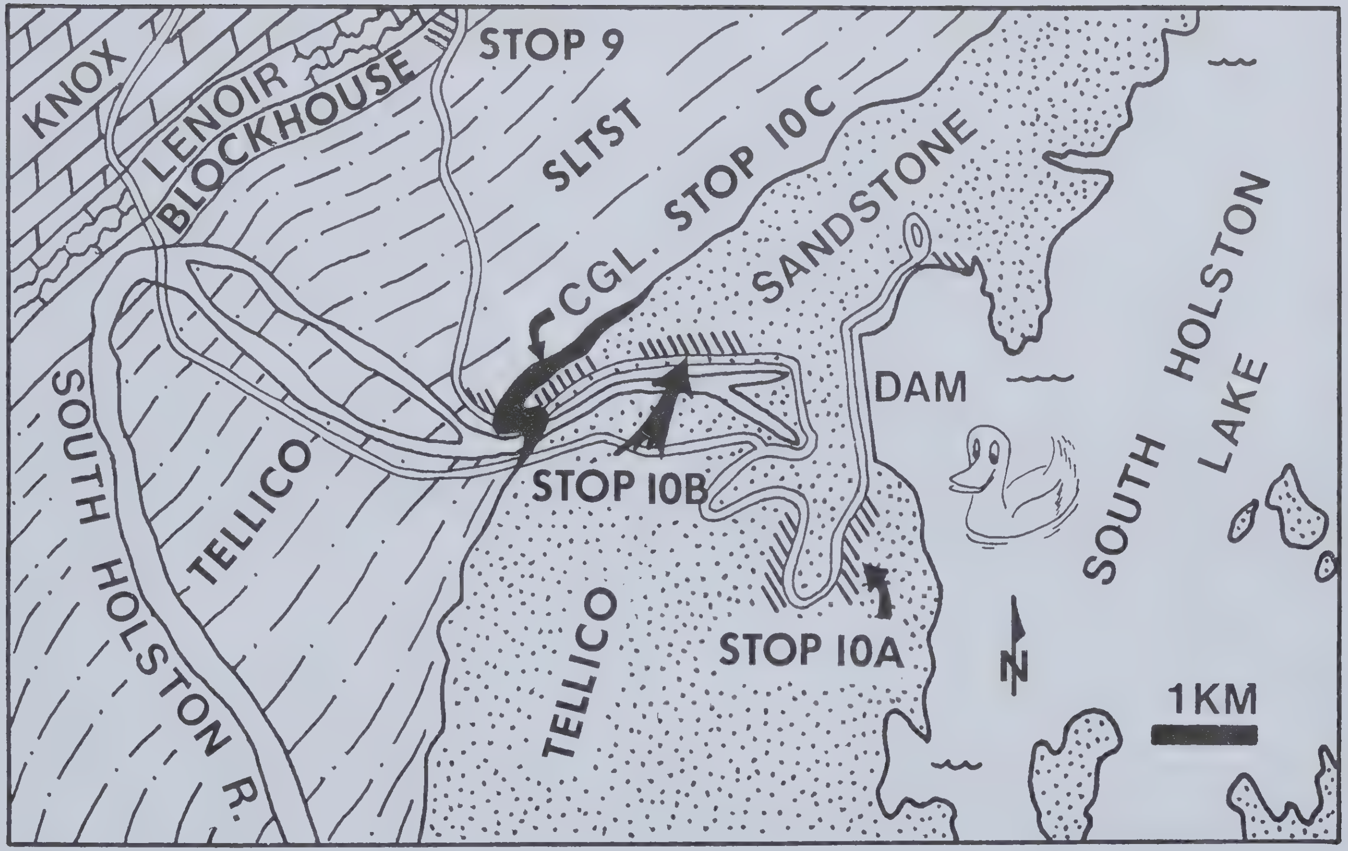


FIGURE 34: Geologic sketch map showing locations of Stops 9, 10A-C and Middle Ordovician stratigraphy in vicinity of South Holston Dam.

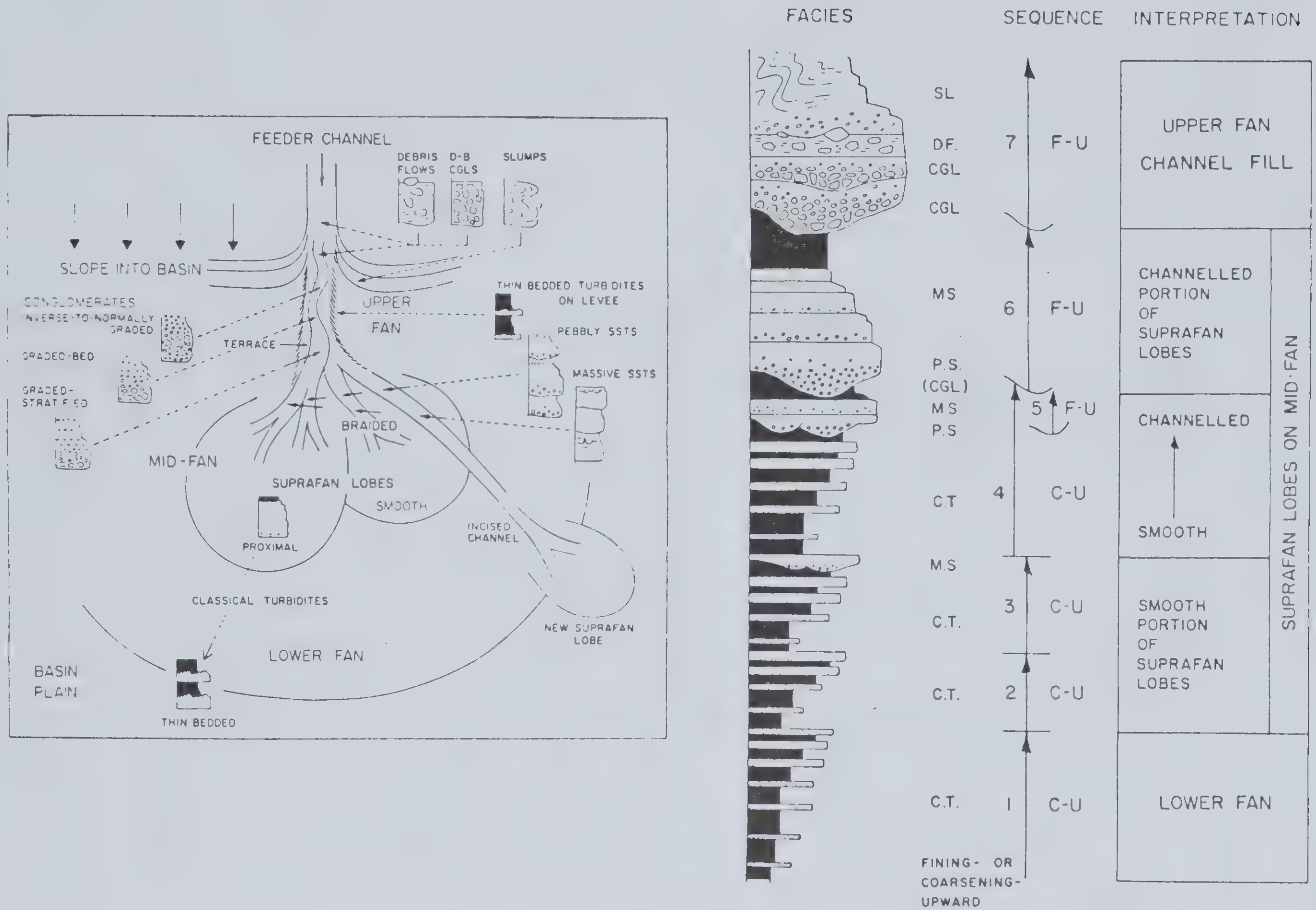


FIGURE 35: Model for submarine fan sedimentation (slightly modified from Walker, 1978.)
Left: Map view showing facies distribution and associated lithotypes.
Right: Ideal vertical section through prograding fan.

In the following presentation, we will travel stratigraphically down section from the most proximal facies present at South Holston Dam (mid-fan; Stop 10A) through the outer (distal) fan (Stop 10B) to the fan-toe area of incised conglomerate channels and ultradistal turbidites (Stop 10C), which overlie the basinal shales of the Blockhouse.

STOP 10A: SUPRAFAN DEPOSITS IN THE TELLICO FORMATION

The most proximal fan facies observed in the outcrops at Holston Dam are mid-fan sediments exposed in lake shore cliffs immediately east of the picnic area, and in road cuts at this stop and along the access road south of the dam. The mid-fan area, often referred to as the suprafan, is morphologically characterized as a convex-upward depositional bulge composed of overlapping lobate sediment bodies deposited from shifting and often braided distributary channels. The major lithotypes deposited in suprafan channels are lenticular and coalesced pebbly and massive sandstones, as well as thin-bedded classical turbidites with partial Bouma sequences. These deposits commonly form thinning and fining upward packages that result from progressive abandonment of individual distributaries during channel or lobe switching. Interchannel and lower supra-fan deposits consist of sandy to silty classical turbidites and massive sandstones with tabular geometries and thin-layered hemipelagites deposited during interturbidite intervals. Sand-shale ratios are thus intermediate between inner fan deposits and those of the outer fan (described in Stop 10B).

At this stop the major lithotype observed is massive sandstones, which are intercalated with shale in this outcrop. Figure 36 shows the range of observed characteristics of massive sandstones in the Tellico Formation in the Holston Dam area. Typically, these beds exhibit little or no internal size grading; a few show a thin interval of normally graded (rarely inverse-to-normal grading) very coarse sand or granules at the base. Tops of beds are generally sharp and planar, though a few may grade rapidly from fine sand to silt or clay within the topmost 2 or 3 cm. Many of these beds are interlayered with hemipelagic shales that mark inter-turbidite intervals, though massive sandstones also commonly are vertically juxtaposed along scour surfaces (amalgamation surfaces), the interturbidite shale having been removed by erosion that emplaced the next massive sandstone. The upper portions of some beds also exhibit diffuse planar laminae. Walker (1978) regards the depositional mechanism for these beds as a high-concentration turbidity current from which sediment is so rapidly deposited that good grading or traction-current features (such as found in the Bouma sequence for classical turbidites, see Stop 10B) do not have time to develop; during the final stages of emplacement grain flow may also be important, thus further lessening the chance for preservation of these features.

At the north end of this cut several thick massive sandstones form an amalgamated package that overlies a thick sequence of intercalated shale and individual massive sandstone beds. The amalgamated package probably represents the fill of a suprafan channel that has been cut into other suprafan sediments. Figure 37 shows the style of packaging in one of these suprafan channels, located in the lake shore cliffs east of the Picnic Area. The plot of bed number vs. 5 x 5 moving average of bed thickness and the vertical strip log of the interval clearly show the thinning upward nature

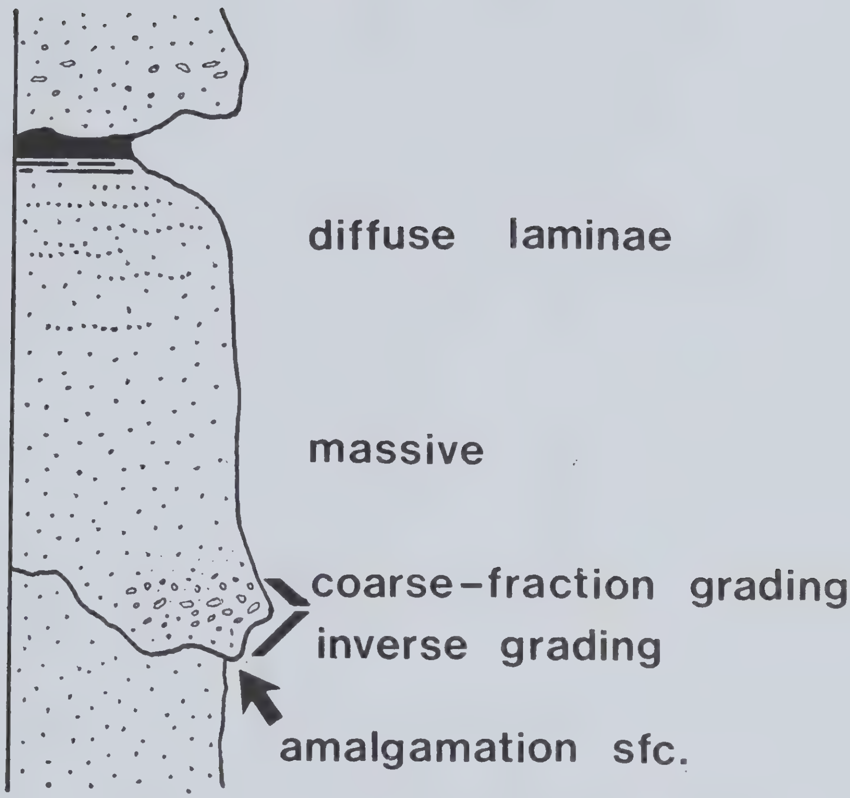


FIGURE 36: Sketch showing characteristics of massive sandstone lithotype at Holston Lake.

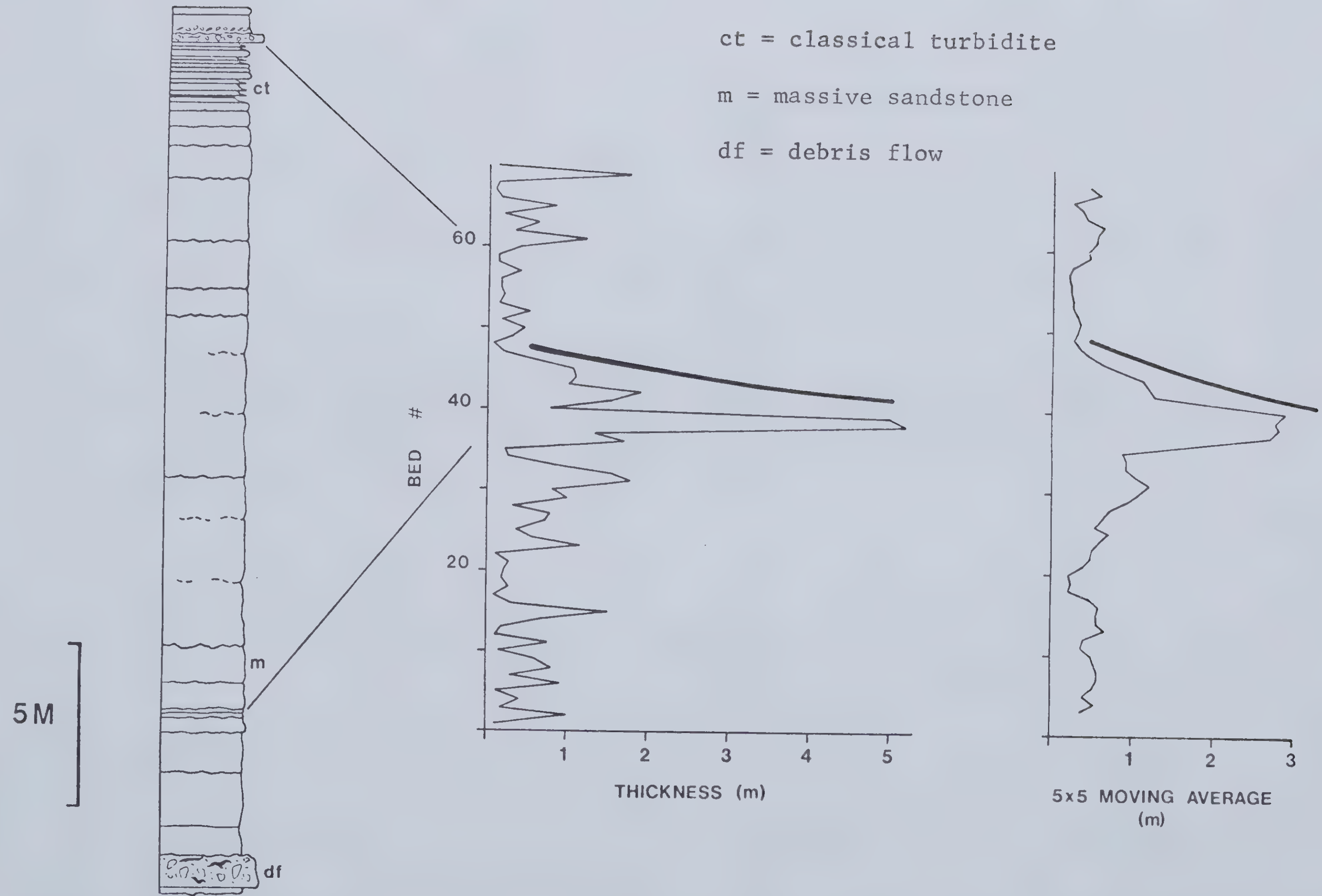


FIGURE 37: Vertical strip log and plots of bed number vs. thickness and 5 x 5 moving average of thickness for suprafan massive sandstone channel-fill.

of channel-fill sediments in the suprafan. In the southern portion of the outcrop before us, a thick sequence of shale and thinner massive sandstones, with a few classical turbidites probably represent interchannel deposits and the smooth, outer portion of the suprafan.

ROAD LOG

Interval	Cumulative	
	128.5	Reboard bus. Proceed south on South Holston Dam Access Road.
0.3	128.8	Outcrops of suprafan sandstone and shale in Tellico Formation on left (west) side of road. Proceed toward base of Dam on Access Road.
0.6	129.4	South Access Road enters on left; continue toward Dam.
0.2	129.6	Center of base of Dam.
0.2	129.8	Stop 10B at roadcuts on the right (north) side of North Access Road from 200 to 400 m west of Dam. We will reboard the bus at the west end of the outcrop.

STOP 10B: DISTAL FAN DEPOSITS IN THE TELLICO FORMATION

The outer fan is a topographically smooth, low-gradient area that merges with the basin plain. This region is characterized by deposition of thin to thick-bedded classical turbidites, hemipelagites, and thin, laminated silty or clay-rich turbidites (ultradistal; Shanmugam and Walker, 1978). These beds are typically fine-grained and form tabular or sheet-like and monotonous deposits. Sand-shale ratios are typically low but increase from the outer fan edge toward suprafan deposits sympathetically with increases in turbidite bed thicknesses and grain size. Coarsening and thickening upward packages of beds are common within outer fan deposits (as well as the outer, smooth portions of suprafan lobes) and result from suprafan lobe progradation.

The major lithotype present in this outcrop is the classical turbidite (see fig. 38), which ideally exhibits the vertical sequence of structures established by Bouma (1962). Table 1 gives the frequencies of different partial and complete Bouma sequences present in this exposure; note that complete Bouma sequences [ABC(D)] are rare (less than 1% in abundance), whereas (D) sequences are the most abundant, which is suggestive of a somewhat distal position on the fan. Nearly all of these beds have tabular geometries, and their thicknesses vary only slightly along individual bedding exposures.

Dark, thinly laminated shale is intercalated with the turbidites in this exposure. The bulk of the shale is thought to result from suspension fall-out from the tails of turbidity currents and from hemipelagic sedimentation between turbidite episodes. A few of the thicker silty layers

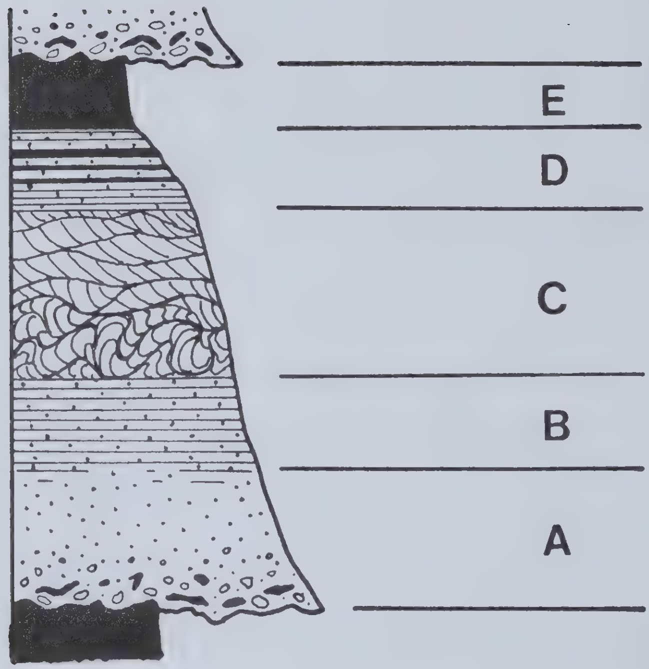


FIGURE 38: Ideal Bouma sequence in classical turbidites.
A, basal graded division.
B, upper flow regime planar laminae.
C, Ripple or climbing ripple cross-laminae with or without convolutions.
D, Lower flow regime planar laminae.
E, Suspension fall-out and hemipelagic division.

Table 1. Data on turbidite beds at Stop 10B

Type	Number	Numerical %	Mean Thickness Cm.
A	18	3.1	20.13
ABC[D]	4	0.7	39.25
AC[D]	54	9.4	33.96
A[D]	85	14.7	26.6
B[D]	1	0.1	58.0
C[D]	50	8.7	12.84
[D]	365	63.3	9.0

are graded and probably represent deposition from low concentration, ultra-distal silt and clay-rich turbidity currents. Many bedding surfaces in the shale also exhibit fine parallel and linear rib and furrow patterns (longitudinal rib and furrow), which are erosional features of weakly consolidated mud bottoms that formed with their longest dimensions parallel to the direction of bottom currents that periodically swept the area.

The dominant style of lithologic packaging in this exposure is a series of thickening upward packages of sandstone and shale, in which the sand-shale ratios increase upward toward the top of the packages. Figure 39 shows two typical examples; the plot of vertical ordination of beds (Bed number) vs. thickness and vs. the 5 x 5 moving average of thickness (which smoothes out irregularities in the thickness curve) clearly show the packages, which average about 5 m. in thickness. A vertical strip log of the interval is shown for visual comparison. These packages are interspersed with thick fine-grained intervals composed of shale and thin-layered DE-interval turbidites that show no vertical trends in thickness. The tabular, non-channelized nature of the turbidites in this exposure, their relatively fine grain size, and the presence of thickening upward packages in the section are evidence that these beds were deposited within the distal fan to outer, smooth portion of suprafan lobes.

Paleocurrent data in this exposure (see fig. 40) indicate that currents flowed from the southeast. These data were accumulated from bedding surface exposures of large ripples within the C-interval of the thicker turbidites. Average ripple height is about 3 cm., and ripple spacing is from 5 to 10 cm. The consistency index for these data is high (r = 0.92; method of Rao and Sengupta, 1972) and indicates a high degree of confidence in the southeastern source direction of these beds, which fits the regional structural and stratigraphic framework presented earlier.

ROAD LOG

Interval	Cumulative	
0.1	129.9	Reboard bus. Proceed westward on North Access Road.

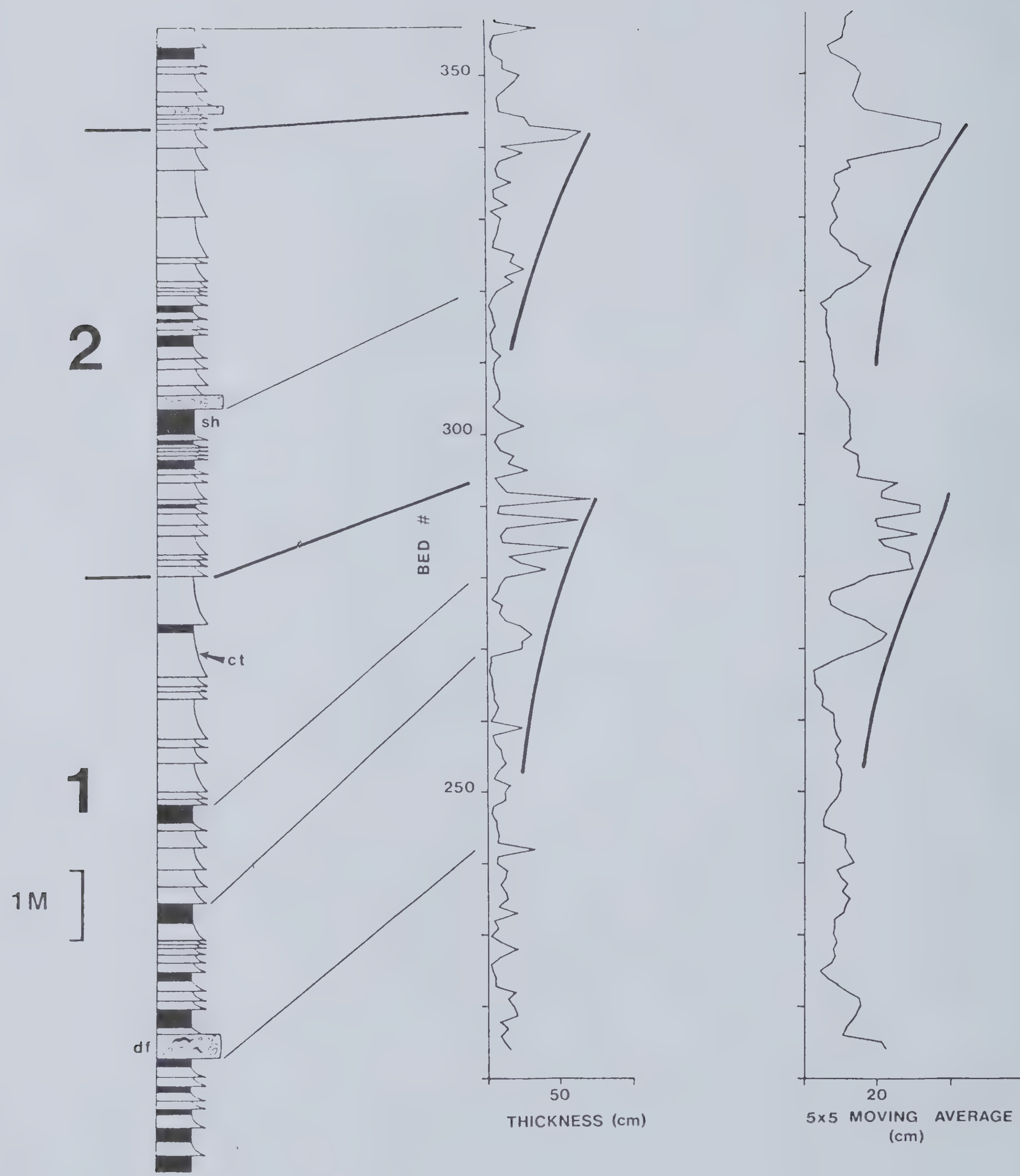


FIGURE 39: Vertical strip log and plots of bed number vs thickness for distal fan classical turbidites. df, debris flow; ct, classical turbidite; sh, shale.

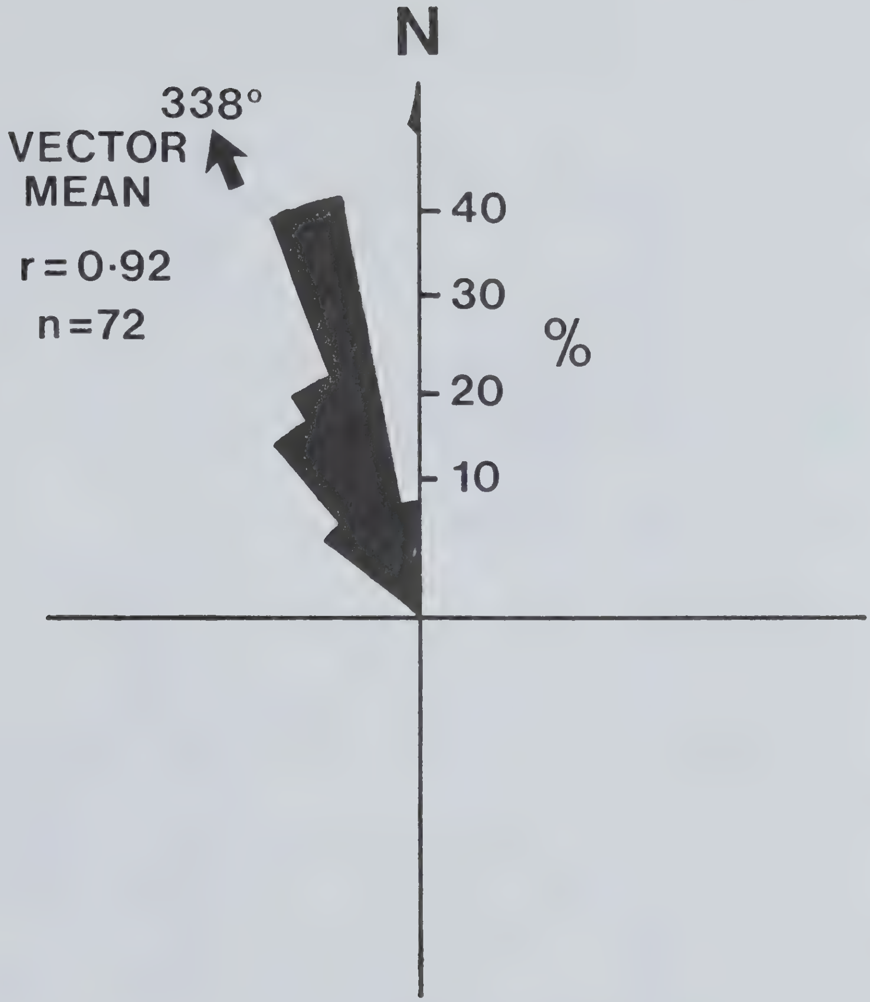


FIGURE 40: Paleocurrent rose and vector mean orientation for 72 turbidites in distal fan deposits, Stop 10B.

Interval	Cumulative	
0.2	130.1	Stop 10C at outcrops of conglomerate and ultradistal turbidites in the Tellico Formation on the north side of the North Access Road. We will reboard the bus at the western end of the outcrop, which is about 500 m. long.

STOP 10C: INCISED FAN-CHANNEL CONGLOMERATE AND ULTRADISTAL TURBIDITES IN THE TELLICO FORMATION

This exposure, which is located stratigraphically beneath distal fan deposits described at Stop 10B, is composed of two environmental units. The first unit, located in the eastern half of the exposure, is a sequence of coarse, dominantly clast-supported conglomerates interpreted as an incised distal fan channel-fill. The second unit, in the western half of the exposure, is a thick sequence of ultradistal silt and clay turbidites that overlie the Blockhouse hemipelagites at the base of the basin-fill.

Incised Channel-Fill Conglomerate

During fan progradation, progressive abandonment or rapid plugging of inner suprafan channels may divert several successive flows down and across steeper gradients along the flanks of the fan. This process, avulsion, causes incision of a new channel across the fan to its more distal reaches and causes diversion of much coarse material from the inner fan region. Such incised channels result in the anomalous juxtaposition of conglomeratic inner fan lithotypes with distal or outer fan deposits.

The conglomerate unit at South Holston Dam is a lenticular, channel-form body that extends for roughly 2 km. along strike and is approximately 35 m. thick in roadcut exposure. These dimensions compare well with channel sizes recorded from many modern deep-sea fans (Normark, 1970, 1974, 1978). The base of the unit lies sharply above the silt turbidites at the base of the section to the west, though minor slumping and weathering in the roadcut have all but obscured it from view.

The bulk of the sequence is composed of two major types of conglomerate--clast-supported, and matrix-supported varieties. Figure 41 illustrates the characteristics of these beds. Clast-supported varieties range from those in which no grading, imbrication, or stratification is visible (disorganized bed) to those containing clasts, imbricated or non-imbricated, that exhibit inverse-to-normal size grading, simple normal grading, and normal graded intervals above which crude cross-stratification and planar stratification (graded-stratified bed) are visible. All beds are markedly lenticular or channel-form, attesting to the strong erosive power and active, migratory nature of the flows within the channel. Walker (1975, 1978) has suggested that the progression of conglomerate types as listed in order above may document proximal to more distal reaches of fan channels, though no one bed may be observed to exhibit all of these transitions down depositional dip. Arrows between clast-supported varieties in figure 41 emphasize this transition, which as well occurs upward vertically within the conglomerate unit.

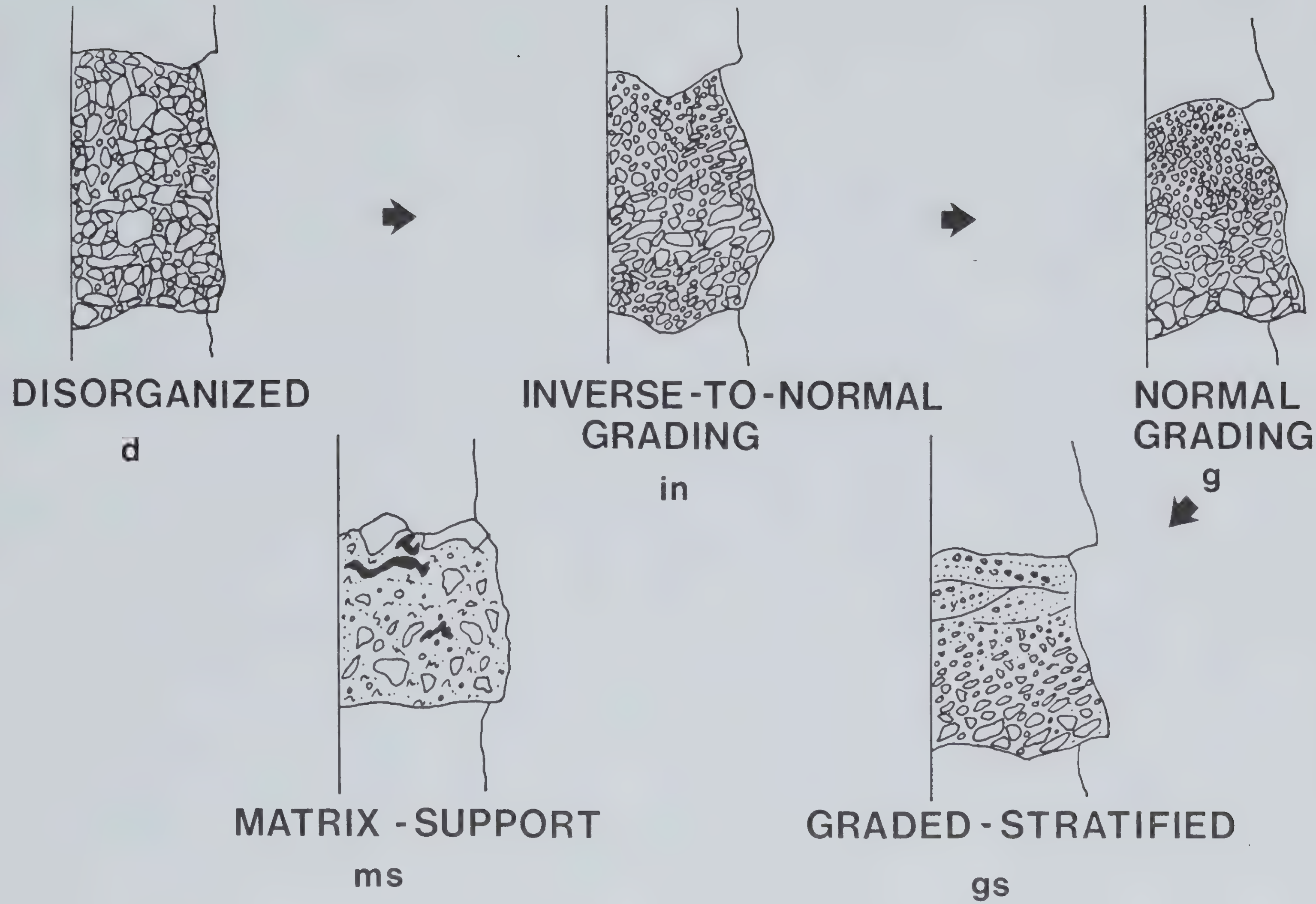


FIGURE 41: Characteristics of clast and matrix-supported resedimented conglomerates (after Walker, 1978). Arrows emphasize proximal (disorganized) to distal (graded-stratified) scheme of conglomerate deposition according to R. G. Walker.

Matrix-supported conglomerates are those in which clasts are generally suspended in a clayey to sandy matrix and in which clast imbrication, stratification, and grading are weak to absent. Most are interpreted as the deposits of viscous debris flows. A few of these types of beds may exhibit marked inverse size grading near their tops, with clasts that project above the upper surface of the bed and give it an irregular, hummocky appearance (e.g., Johnson, 1970; Fisher, 1971; Middleton and Hampton, 1976). At South Holston Dam, only 1 bed (labelled m-s/d in fig. 43) is inferred to be a debris flow. It exhibits characters transitional between a disorganized, clast-supported bed and a true matrix-supported bed. Near the top of the bed a sharp zone of inverse grading may be observed beneath a hummocky upper surface of projecting clasts. Maximum clast size is up to 1 m. in diameter. Numerous large rafted intraformational shale clasts are scattered throughout the bed, though the largest of these are concentrated in the upper part of the bed. These clasts, being less dense than the other types, may have been supported at higher levels in the flow because of increased matrix strength and their buoyancy within the flow, which is interpreted as a debris flow.

The upper part of the channel-fill sequence is dominated by massive as well as pebbly sandstones. The characteristics of massive sandstones have already been described in Stop 10A. Pebbly sandstones (see fig. 42) are a lithotype transitional between graded-stratified beds and massive sandstones. They generally exhibit a clast-supported, normally graded (rarely inverse-to-normally graded) and imbricated gravel overlain by a massive or planar-stratified interval of sandstone. Contacts between successive layers are highly erosive, and several beds may be amalgamated. At the bases of some layers, load and slump structures may also be observed. This sequence is capped by several thin-bedded classical turbidites and interlayered hemipelagic shale.

Figure 43 illustrates the vertical succession of lithotypes and thickness variations within the conglomerate sequence. A pronounced thinning and fining upward sequence is demonstrated by the vertical strip-log and plot of bed thickness vs. bed number. This package, with its sharp base, lenticular and channel-form occurrence, and the observation that it is sandwiched between ultra-distal and distal fan deposits, is thus interpreted as an incised distal fan channel-fill sequence.

The conglomerates in this sequence are polymict. Clasts of most of the stratigraphically subjacent units of the Valley and Ridge down to the Precambrian section may be found (Kellberg and Grant, 1956). These include clasts of Lenoir-like lithologies, the Knox Dolomite, various limestones of the Cambrian Conasauga Group, gray and green sandstones and arkosic granule conglomerate of the Cambrian Chilhowee Group, dark gray and olive-drab chert, dark metarhyolite of the Precambrian Mount Rogers Group, siltstone, and milky-white vein quartz. Thus a nearly complete stratigraphic sequence nearly 8 to 10 km. thick (maximum thickness of the lower Cambrian through the lower Ordovician section) must have been uplifted in the source area; this uplift is clear evidence of Taconic deformation during the basin's development.

Ultradistal Turbidites

The west side of this outcrop contains an abundance of thin to

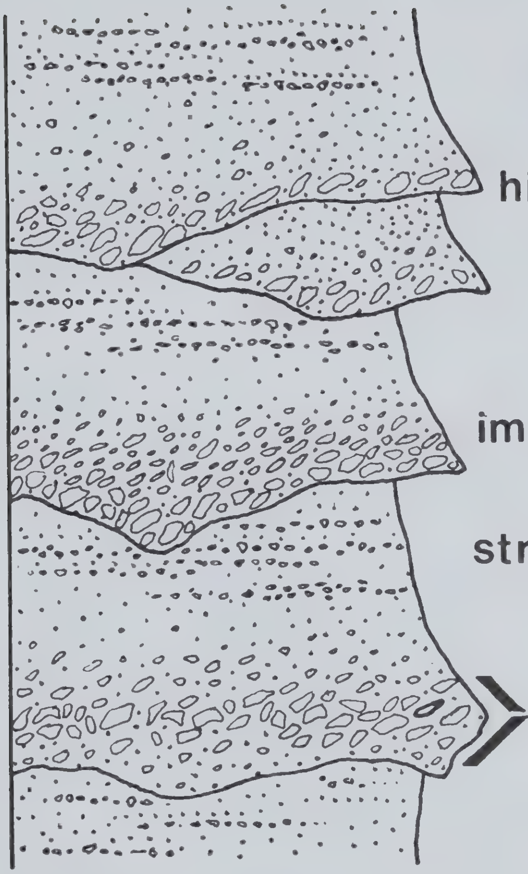


FIGURE 42: Characteristics of pebbly sandstone lithotype at South Holston Lake. Note interval of inverse-to-normal grading at base of lowermost bed.

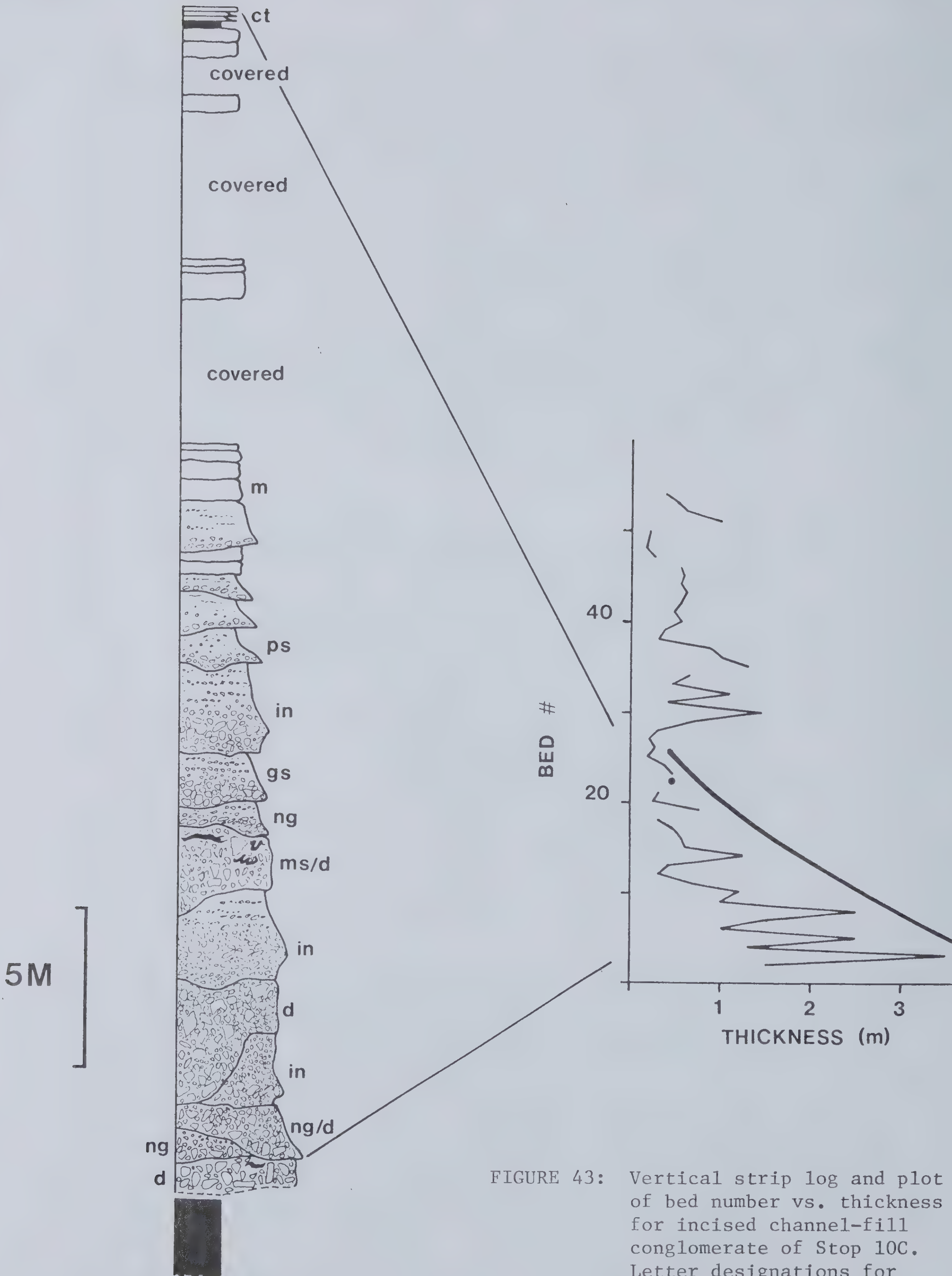


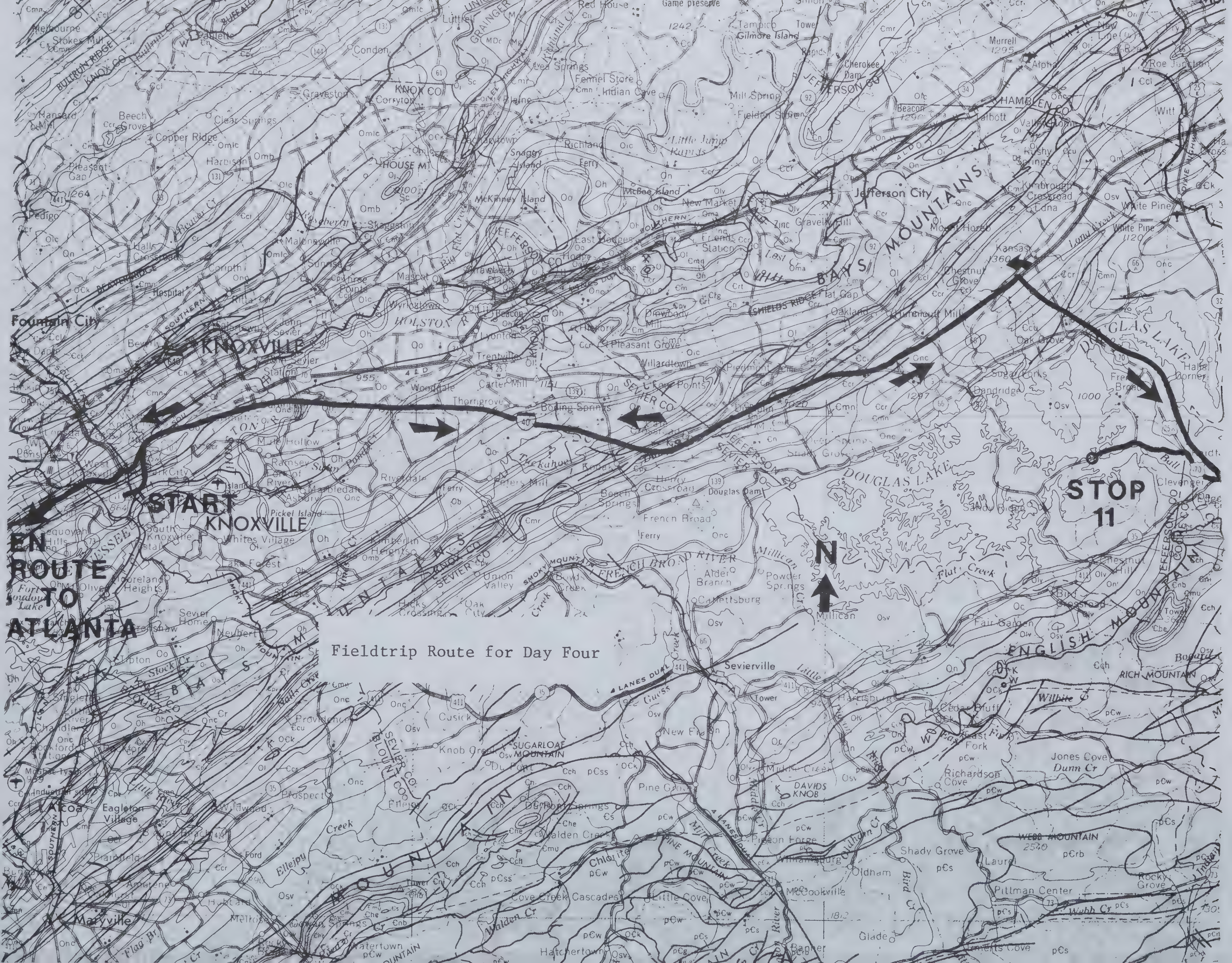
FIGURE 43: Vertical strip log and plot of bed number vs. thickness for incised channel-fill conglomerate of Stop 10C. Letter designations for conglomerates in strip log are presented in figure 41.

thick-layered ultradistal silt and clay-rich turbidites. Each layer is graded from light gray, coarse to fine silt to dark gray clay shale, which probably represents interturbidite hemipelagic deposition, at the top. Basal contacts of the layers are sharp, and locally microscopic load casts, scour, or flame structures may be observed with a hand lens. The basal portions of several of the thicker layers exhibit thin planar laminae or microscopic cross-laminae of coarse silt, so that these beds represent the DE and CDE portions of the Bouma sequence. Similar features were observed in ultradistal turbidites at Boyds Creek by Shanmugam (1978).

In general, layer thicknesses increase upward stratigraphically within the deposit toward the conglomerate, and a few thin fine sandstone layers are interbedded with the siltstones near the base of the conglomerate channel-fill. This coarsening and thickening upward probably results from progradation of the fan complex, so that these beds are interpreted to represent the ultradistal fan-edge and turbidite portion of the basin plain, which overlies the basinal hemipelagites of the Blockhouse.

ROAD LOG

Interval	Cumulative	
0.2	130.3	REBOARD BUS at western end of outcrops at Stop 10C, proceed westward on North Access Road.
2.4	132.7	Intersection with U. S. Route 421 North. Turn left (west) toward Bristol. Stay on 421 into Bristol.
6.3	139.0	Intersection Route 421 North with Tennessee State Route 381, CONTINUE on U. S. Route 421 North.
1.0	140.0	Intersection of Route 421 North with U. S. Route 11 W. Turn left onto 11 W toward Interstate Route 81 South.
2.9	142.9	Intersection Route 11 W with Interstate Route 81. Enter I 81 South toward Knoxville.
49.8	192.7	I 81 South passes over U. S. Route 11 at Bulls Gap Exit, continue southward on Interstate.
21.6	214.3	Interstate 81 South intersects Interstate 40 West. Take exit to I 40 West toward Knoxville.
32.2	246.5	Exit I 40 West at Business Loop.
1.2	247.7	Exit onto Cumberland Avenue.
1.2	248.9	Turn right into 16th Street.
0.1	249.0	Turn left into Clinch Avenue.
0.1	249.1	Intersection Clinch Avenue and 17th Street, END DAY THREE.



Fieldtrip Route for Day Four

ROAD LOG

Interval	Cumulative	
	0.0	START. Corner of 17th Street and Cumberland Avenue, proceed east on Cumberland.
0.3	0.3	East-bound Cumberland Avenue becomes Main Street. Continue east on Main.
0.9	1.2	Intersection Business Loop - merge and follow signs to I-40.
0.8	2.0	Exit I-40 east (to Asheville).
13.5	15.5	Midway Road (see STOP 3).
8.0	23.5	Sevier County Line
11.3	34.8	Intersection I-81 north - continue on I-40 east
3.8	38.6	Bridge over French Broad River. Knox Dolomite exposed along shoreline on west side of bridge.
4.9	43.5	Jefferson County line.
2.0	45.5	Exit onto U.S. 25W-70 and proceed right (southwest)
0.8	46.3	Junction U.S. 25W-70 and U.S. 411. Continue west on U.S. 25W-70.
1.4	47.7	Junction Indian Creek Road and U.S. Highway 25W-70. Turn left onto Indian Creek Road and proceed west.
3.1	50.8	Disembark on east side of bridge over Indian Creek. Stop 11.

STOP 11: SUPRAFAN TURBIDITES IN THE TELLICO FORMATION, INDIAN CREEK EMBAYMENT, TENNESSEE

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INTRODUCTION

Coarse and fine-grained sandstone and granule conglomerate are interbedded with shale along the mouth of Indian Creek Embayment in Jefferson County, Tennessee (fig. 44). The Tellico Formation in this area is composed of thick intervals of siltstone and shale that encase laterally

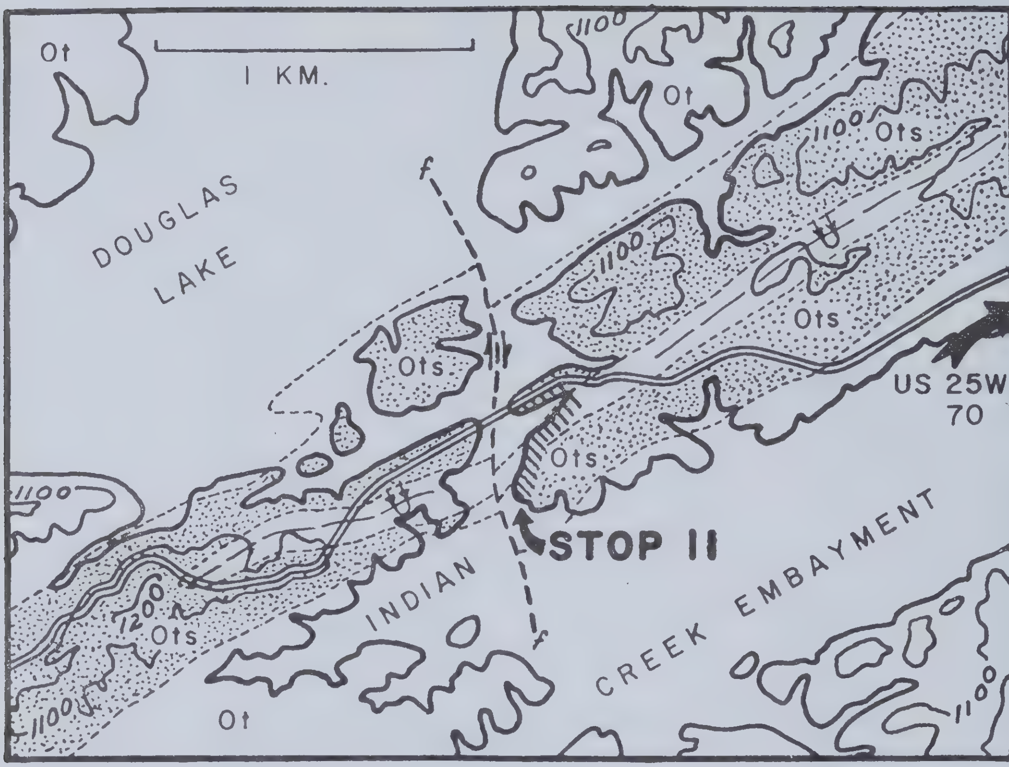

FIGURE 44. Geological map of the Indian Creek Embayment area of Douglas Lake, Tennessee showing the location of the outcrops of Stop 11 (cross-hatched). Ots = sandstone and conglomerate of the Tellico (Ot) Formation.

FIGURE 45. Geological cross-section along the trend of the outcrops of Stop 11.

persistent packages of classical turbidites, massive sandstones, and a few pebbly sandstones (see lithotype descriptions in Stop 10), which are interpreted as suprafan deposits of a submarine fan complex. At this stop, one of the sandstone packages is exposed in a tightly folded and internally complex overturned syncline that strikes E-NE. The overturned section on the south limb of the fold (Fig. 45) is best exposed and is structurally straight forward on the east side of the embayment; it will be observed at this stop.

Suprafan sedimentation (see Stop 10) is characterized by a shifting pattern of active channels and associated depositional lobes. As active loci of deposition change positions, individual depositional lobes are abandoned. Turbidity currents no longer dominate these lobes, and so they become draped by fine-grained hemipelagic shales. The vertical stratigraphic assemblage thus generated by this process is a series of suprafan sandstone bodies formed by active turbidite deposition, encased in thick intervals of fine-grained shales. The Tellico Formation at this stop is interpreted to originate from this style of deposition.

The stratigraphic subdivisions of this section are shown diagrammatically in the cross section of Figure 45. The sandstone package is overlain by thick-bedded ultradistal siltstone turbidites and shale in the core of the fold. Beneath the sandstone package (at the southern end of the cross section in fig. 45) is a thick sequence of shale (not shown) with interlayered, thin-bedded distal (CDE and DE sequence) turbidites. At this locality we will travel stratigraphically down section through the upper shale and siltstone, into the suprafan sandstone, and into the shale beneath the sandstone.

UPPER SHALE UNIT

The bulk of this unit is composed of olive black to medium dark gray clayey shale that is thinly laminated. Sparse graptolites and rare, acrotretid brachiopods thought to be pelagic in origin may be found on some bedding surfaces. Locally within this sequence thin-bedded, graded siltstone beds (ultradistal turbidites), and a few lenticular classical turbidites are interlayered with the clay shale. The bulk of the shale is hemipelagic in origin; the graded siltstones and thin-bedded turbidites probably result from overbank deposition from laterally adjacent, active suprafan channels.

UPPER SILTSTONE UNIT

This unit, which is about 5 m. thick, lies directly above the sandstone package in the overturned south limb of the fold. It is composed entirely of thin (2-4 cm.) graded siltstone - claystone couplets deposited by ultradistal turbidity currents. Some of the clay shale in the upper portions of these layers is doubtless of hemipelagic origin, but it is difficult to distinguish it from the E portions of the turbidites. This sequence grades downward into thin-bedded distal turbidites at the top of the sandstone package and probably represents the final phase of turbidite sedimentation during the abandonment of the suprafan lobe.

SANDSTONE PACKAGE

This unit, which is approximately 75 m. thick, is a complex assemblage of massive sandstones and less abundant classical turbidites deposited in the outer portion of an active suprafan lobe. Shale is interbedded with the turbidites throughout the package but is more important in its upper part, so that the sand-shale ratio decrease progressively upsection.

The classical turbidites in the sandstone package are found predominantly in the top of the sequence. They are fine-grained, tabular to lenticular, and are interlayered with shale. CDE and DE sequences are the most commonly observed intervals of the Bouma sequence, though BCE and a few ACE sequences may also be found. No complete Bouma sequences have been observed in these beds. Load casts and pockets may also be found at the bases of some beds.

Massive sandstones in this unit in general contain all of the characteristics of massive sandstones observed at Holston Dam (Stop 10), though at the present stop they are coarser grained and more clearly graded. Most of the thicker beds exhibit a coarse-fraction graded granular coarse sandstone base that grades continuously upward to medium or fine-grained sandstone at the top. Planar lamination is exhibited in the upper half of most beds, though in some it is only vaguely developed. Many of the beds are markedly lenticular and pinch out laterally within a few meters, especially in the lower half of the package. Load casts, flutes, and groove casts are particularly abundant throughout the package. Additional features of these sandstones, which are not observed in the rocks at South Holston Dam, however, are dish and pillar structures (Lowe, 1975). The dish structures are observed as small parting surfaces subparallel to bedding but gently curved toward the tops of the beds. Locally these structures are tightly cemented and weather out in relief. Pillars are irregular and anastomosing features that lie statistically perpendicular to primary layering in the sandstone, that weather in relief and superfically resemble veins. Both the dishes and the pillars typically occupy the central and upper portions of the massive sandstones. These features are generally interpreted to have formed during dewatering of rapidly deposited sand (Lowe, 1975) and are thought to form during late stages of emplacement of these beds from high-concentration turbidity currents (Walker, 1978).

In numerous places throughout the sandstone section, localized zones 10-20 cm. thick of soft-sediment deformation may be observed. These intervals usually begin within or at the base of a massive sandstone bed and involve several succeeding layers of shale ± thin-bedded classical turbidites or thin massive sandstones. The massive unit at the base of the zone commonly exhibits a hummocky top (or base) in which the overlying shale has been stirred in, so that flame-like projections of sandstone and shale lend a flasered appearance to the contact. The sandstone also may exhibit internal deformation or convolutions, locally with numerous thin, clay-rich and irregular partings sub-parallel to bedding. The overlying shale and thin-layered turbidites are highly load cast, swirled, and locally recumbently folded. The top of the zone is generally shale that is overlain by an undeformed massive sandstone. These intervals are interpreted as zones along which post-depositional

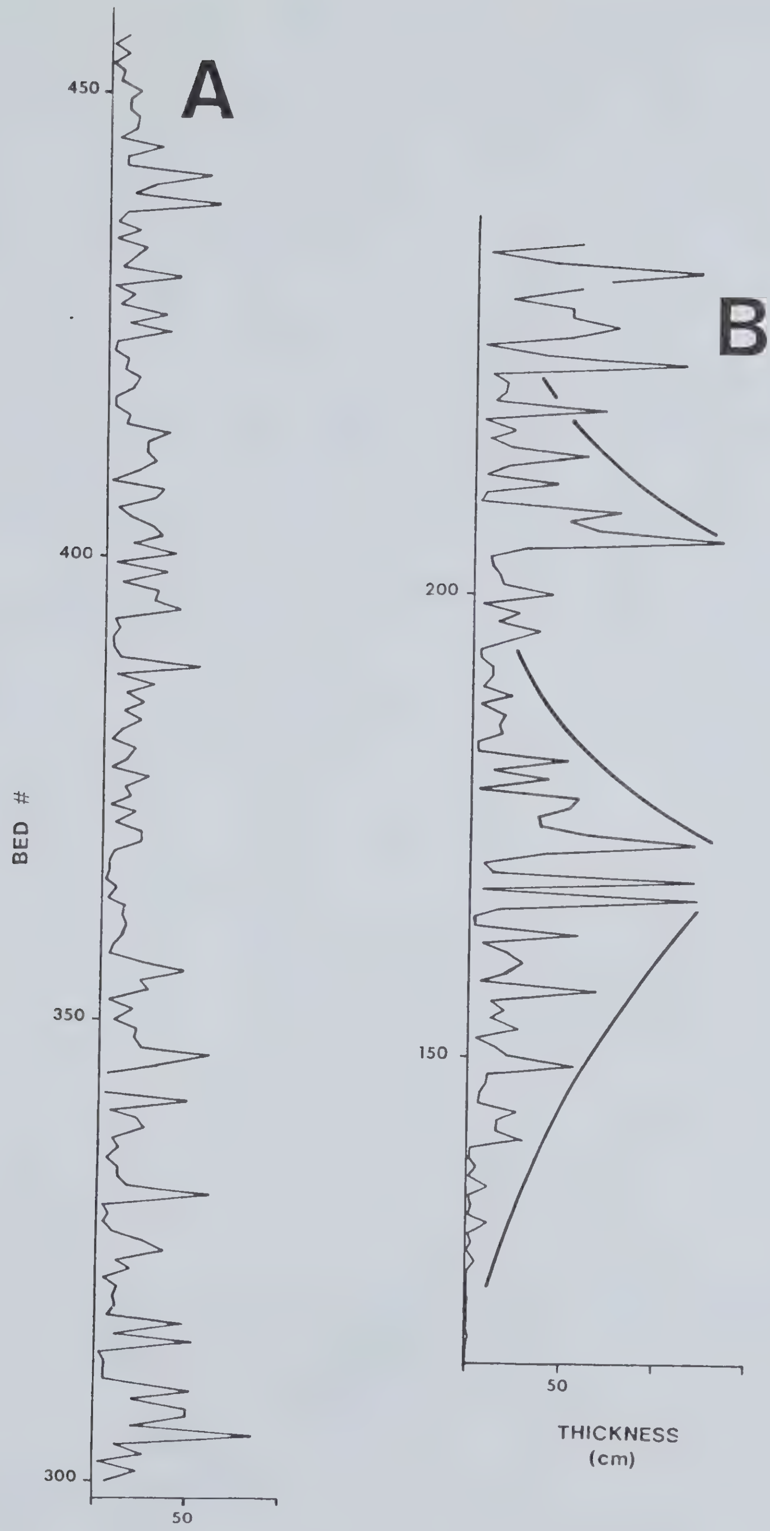

FIGURE 46: Bed number vs. thickness in upper (A) and lower (B) parts of sandstone package at Indian Creek. Note thickening upward cycle followed by thinning upward cycles in B.

liquefaction and sliding has occurred, perhaps as a response to rapid deposition of massive sandstone on a depositional slope. The basal massive sandstone of the zone was probably in an underconsolidated, watery state, and under the stress of rapid deposition, it dewatered, reducing the yield strength of the overlying material and thereby allowing the material to slide under the force of gravity.

Lithologic packaging (fig. 46) within the sandstone is complex. The base of the interval, which grades into the underlying shale, exhibits a single thickening upward cycle that is overlain by two thinning upward sequences containing amalgamated massive sandstones. The thicknesses of the thinning upward cycles are only a few meters, however, so that they probably do not represent the main channels of the suprafan. The upper portion of the sandstone is represented by a single, irregular thinning upward package. As only shallow, localized channels are observed in this section, it is thus interpreted to represent the outer, smooth portion of a suprafan lobe that underwent progressive abandonment.

Paleocurrent data from the massive sandstones are summarized in figure 47. These data were taken from flute and groove casts at the exposed bases of individual beds and indicate a northwestern source area for the turbidites at this stop. While this paleoflow direction appears anomalous, given the stratigraphic framework previously discussed, it should be stressed that these rocks occupy a position near the center of the Sevier

FIGURE 47. Paleocurrent rose for groove casts (dashed) and flutes (arrows) from 10 massive sandstones at Indian Creek.

basin axis. Data previously summarized by K. R. Walker (Figure 4, see paleobathymetric maps for T_2 and T_3) suggest that in addition to a southeastern clastic source for the Sevier basin turbidites, sediments were probably also funnelled northwestward down the basin axis. Local topographic irregularities as well as a divergent paleoflow system on a fan elongated parallel to the basin axis may easily account for the anomaly in paleocurrents observed at this stop.

LOWER SHALE UNIT

Stratigraphically below the sandstone package is an undetermined thickness of thinly laminated, graptolite-bearing hemipelagic shale and ultradistal graded siltstone that in all respects resemble the Upper Shale Unit of this stop. Near the exposed base of this section very thin-bedded distal turbidites are interbedded with the shale. Most of these beds are lenticular, less than 10 cm. thick and fine to very fine-grained. The bulk of these contain DE and CDE sequences, and probably represent interchannel or distal fan deposits.

ROAD LOG

Interval	Cumulative	
	49.2	Reboard bus and proceed east on Indian Creek Road.
3.1	52.3	Junction, Indian Creek Road and U.S. Highway 25W-70. Turn right (east) onto U.S. 25W-70.
1.4	53.7	Junction, U.S. 25W-70 and U.S. 411. Continue straight (east) on U.S. 25W-70.
0.4	54.1	Interchange of Interstate 40 and U.S. 25W-70. Proceed toward Knoxville on Interstate 40.
10.6	64.7	Exit ramp to Interstate 81 to Bristol. Proceed straight (west) on Interstate 40 toward Knoxville.
33.3	98.0	Intersection I-40 and Business Loop. Continue west to intersection I-40 and I-75. Exit onto I-75 south (to Atlanta). END OF FIELD TRIP; EN ROUTE TO ATLANTA.

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